Sources of Phosphorus in Stormwater and Street Dirt From Two Urban Residential Basins in Madison, Wisconsin, 1994-95

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By R.J. Waschbusch, W.R. Selbig, and R.T. Bannerman

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Cover photos (clockwise from upper left): street sampler, driveway sampler, lawn sampler, and roof sampler.

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	0.4048	hectare
square mile (mi^2)	2.590	square kilometer
pound (lb)	453.6	gram
ton (short)	0.9072	megagram (Mg)
quart (qt)	0.9463	liter

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

°F = 1.8 (°C) + 32.

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (mg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Other units of measurement used in this report are microsiemens per centimeter at 25°Celsius (µS/cm), micrometers (µm), and bacteria colonies per 100 milliliters of water sample (col/100 mL).

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By R.J. Waschbusch[1], W.R. Selbig[1], *and* R.T. Bannerman[2]

Abstract

Eutrophication is a common problem for lakes in agricultural and urban areas, such as Lakes Wingra and Mendota in Madison, Wisconsin. This report describes a study to estimate the sources of phosphorus, a major contributor to eutrophication, to Lakes Wingra and Mendota from two small urban residential drainage basins. The Monroe Basin empties into Lake Wingra, and the Harper Basin into Lake Mendota. Phosphorus data were collected from streets, lawns, roofs, driveways, and parking lots (source areas) within these two basins and were used to estimate loads from each area. In addition to the samples collected from these source areas, flow-composite samples were collected at monitoring stations located at the watershed outfalls (storm sewers); discharge and rainfall also were measured. Resulting data were then used to calibrate the Source Loading and Management Model (SLAMM, version 6.3, copyright 1993, Pitt & Vorhees) for conditions in the city of Madison and determine within these basins which of the source areas are contributing the most phosphorus.

Water volumes in the calibrated model were calculated to within 23 percent and 24 percent of those measured at the outfalls of each of the basins. These water volumes were applied to the suspended-solids and phosphorus concentrations that were used to calibrate SLAMM for suspended-solids and phosphorus loads. Suspended-solids loads were calculated to be within 4 percent and 17 percent, total-phosphorus loads within 24 percent and 28 percent, and dissolved-phosphorus loads within 9 percent and 10 percent of those measured at the storm-sewer outfall at the Monroe and Harper basins, respectively.

Lawns and streets are the largest sources of total and dissolved phosphorus in the basins. Their combined contribution was approximately 80 percent, with lawns contributing more than the streets. Streets were the largest source of suspended solids.

Street-dirt samples were collected using industrial vacuum equipment. Leaves in these samples were separated out and the remaining sediment was sieved into >250 µm, 250-63 µm, 63-25 µm, <25 µm size fractions and were analyzed for total phosphorus. Approximately 75 percent of the sediment mass resides in the >250 µm size fractions. Less than 5 percent of the mass can be found in the particle sizes less than 63 µm. The >250 µm size fraction also contributed nearly 50 percent of the total-phosphorus mass and the leaf fraction contributed an additional 30 percent. In each particle size, approximately 25 percent of the total-phosphorus mass is derived from leaves or other vegetation.

INTRODUCTION

Eutrophication is a common problem for lakes in agricultural and urban areas, such as Lakes Wingra and Mendota in Madison, Wis. Primary productivity in northern temperate lakes is most often limited by phosphorus (Schindler 1974; 1977). Urban runoff has been noted to contain high phosphorus concentrations (U.S. Environmental Protection Agency, 1983) that may be increasing the eutrophication. The focus of the study described in this report was to estimate the sources of phosphorus to Lakes Wingra and Mendota from two small urban residential watersheds in Madison, Wis. (fig. 1). This study was done in cooperation with the city of Madison and the Wisconsin Department of Natural Resources.

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[1] U.S. Geological Survey, Middleton, Wis.
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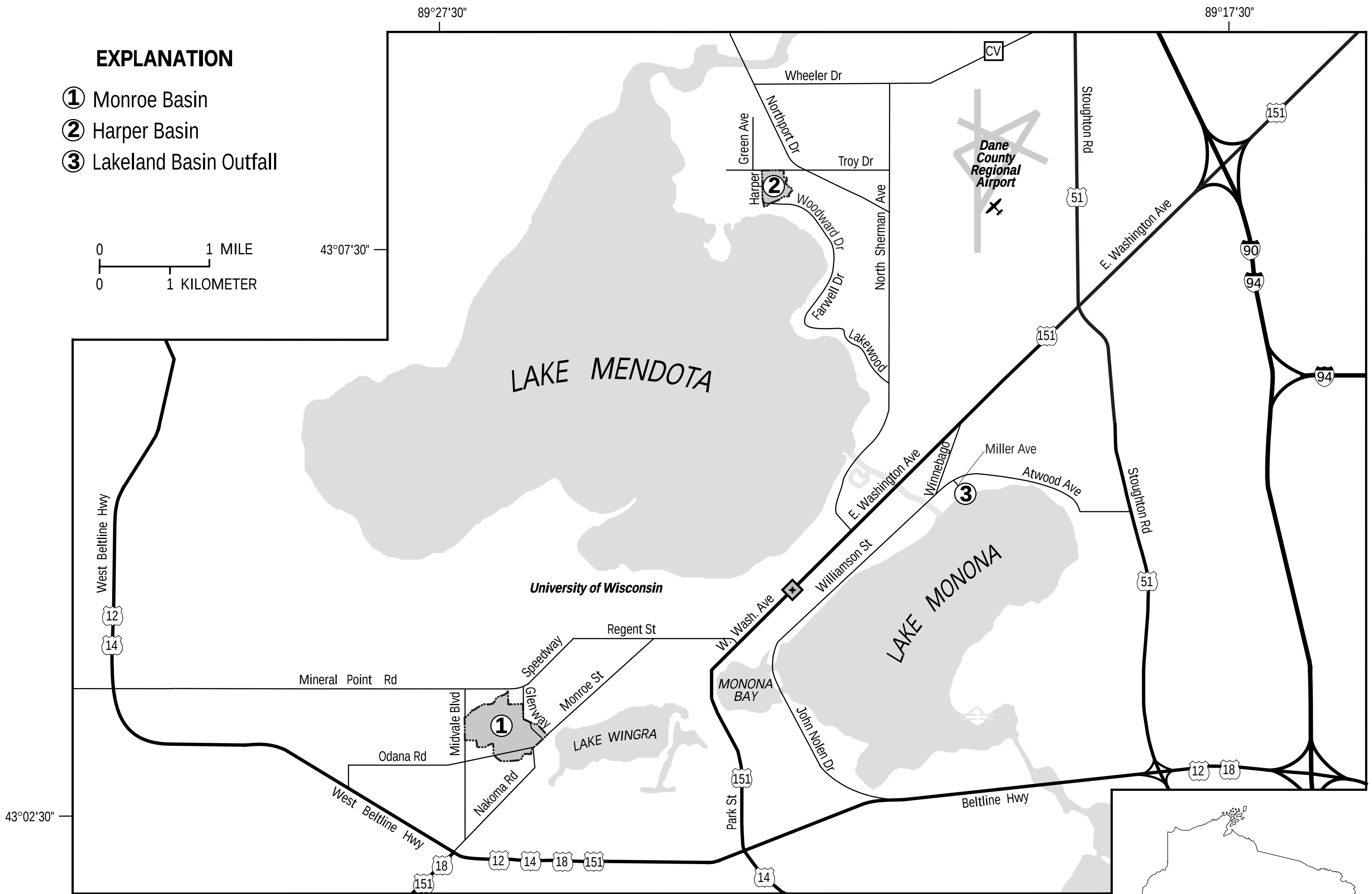

Modified from City of Madison, 1996

Figure 1. Locations of monitored basins for urban runoff sampling in Madison, Wis., 1994–95.

Table 1. Land-use characteristics of the Monroe Basin, 1994, and Harper Basin, 1995, in Madison, Wis.
[--, source not present]

Source area	Monroe Basin				Harper Basin	
	Residential		Commercial		Residential	
	Acreage	Percent of basin	Acreage	Percent of basin	Acreage	Percent of basin
Lawn	119.8	51.5	--	--	23.6	57.4
Roof	26.5	11.4	2.3	1.0	5.4	13.2
Street	30.5	13.1	1.6	.7	5.3	13.0
Woodlot	--	--	--	--	3.0	7.3
Driveway	10.6	4.6	--	--	2.1	5.1
Park land	19.3	8.3	--	--	.7	1.7
Sidewalk	12.5	5.4	--	--	.7	1.7
Parking lot	.4	.2	3.4	1.5	.3	.7
Railroad bed	5.3	2.3	--	--	--	--
Total	224.9	96.8	7.3	3.2	41.1	100

Lake Mendota and Lake Wingra are both part of the Wisconsin Department of Natural Resources (WDNR) Priority Watershed Program (Betz and others, 1997). State funding is available to help pay for management aimed at reducing the amounts of phosphorus and other pollutants discharged to the lakes. The goal of the Lake Mendota Priority Watershed Project is to reduce the frequency of nuisance algae blooms in the lake from one out of every two days to one out of every five days. To accomplish this goal, it is estimated that a 50-percent reduction is needed in the amount of phosphorus entering the lake (Betz and others, 1997). To help reach this target, the Nonpoint Source Control Plan for the Lake Mendota Priority Watershed Project (Betz and others, 1997) set an objective of reducing phosphorus loading to the lake by 20 percent from urban areas. The remaining 30-percent reduction is intended to come from rural phosphorus management.

For this study, phosphorus data were collected from five source areas—streets, lawns, roofs, driveways, and parking lots—within the two drainage basins from urban residential and commercial areas to estimate loads from each source area (table 1). Resulting data were used to calibrate the Source Loading and Management Model (SLAMM, version 6.3, copyright 1993, Pitt & Vorhees) for conditions in the city of Madison and determine which source areas are contributing the most phosphorus within these basins. The city is planning to use SLAMM to target specific source areas for management efforts to meet the 20-percent phosphorus-reduction objective of the priority watershed project and to meet requirements of its Wisconsin Pollutant Discharge Elimination System stormwater permit.

Stormwater-runoff samples from source areas and the basin outfall were collected from a medium-density residential watershed draining to Lake Wingra from May to November 1994 and from a medium-density residential watershed draining to Lake Mendota from June to November 1995. These runoff samples were used to estimate the phosphorus and suspended-solids load that each of these source areas and basins contributes. In addition, a third basin, the Lakeland Basin that drains into Lake Monona, was monitored for lawn runoff in 1995. This basin, which encompasses an older section of Madison, was sampled in an attempt to determine whether any difference exists between this section of the city (which has older, smaller lawns) and other areas of the city.

Study-Area Description

The Monroe Basin, monitored during 1994, drains into Lake Wingra. The basin is 232.2 acres, of which 224.9 acres are residential and 7.3 acres are commercial (fig. 2). Lake Wingra has a surface area of 338.9 acres (1.37 km^2) and a drainage area of 3,889 acres (15.74 km^2). About 75 percent of the Lake Wingra drainage basin is urbanized and about 25 percent is composed of forest, prairie, and marsh within the University of Wisconsin Arboretum (Oakes and others, 1975).

The Harper Basin, monitored during 1995, drains into Lake Mendota. The Harper Basin is 41.1 acres, all of which is residential land use (fig. 2). Lake Mendota has a surface area of 9,859 acres (39.9 km^2) and has a

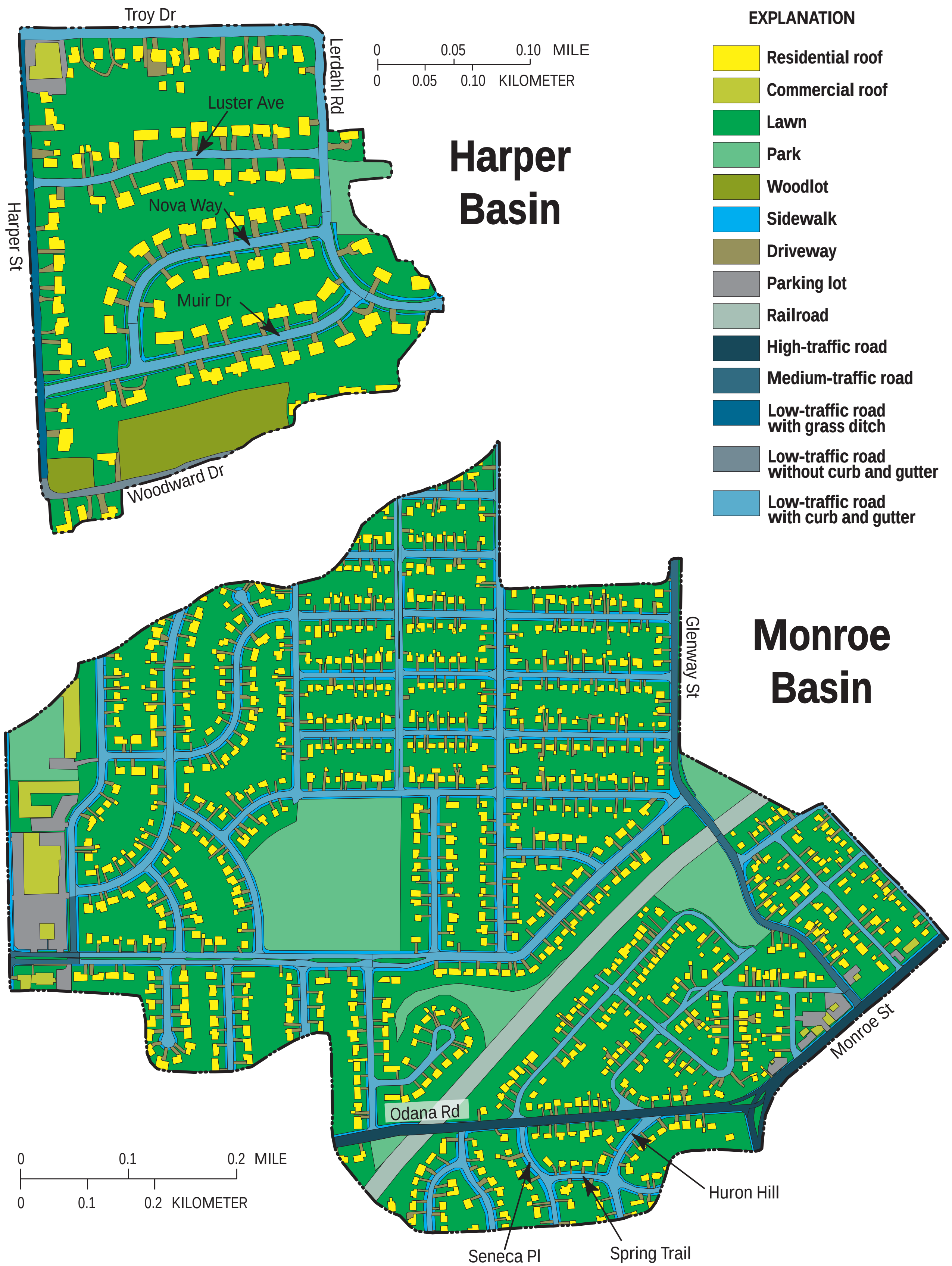

Figure 2. Land-use maps for the Monroe and Harper Basins in Madison, Wis.

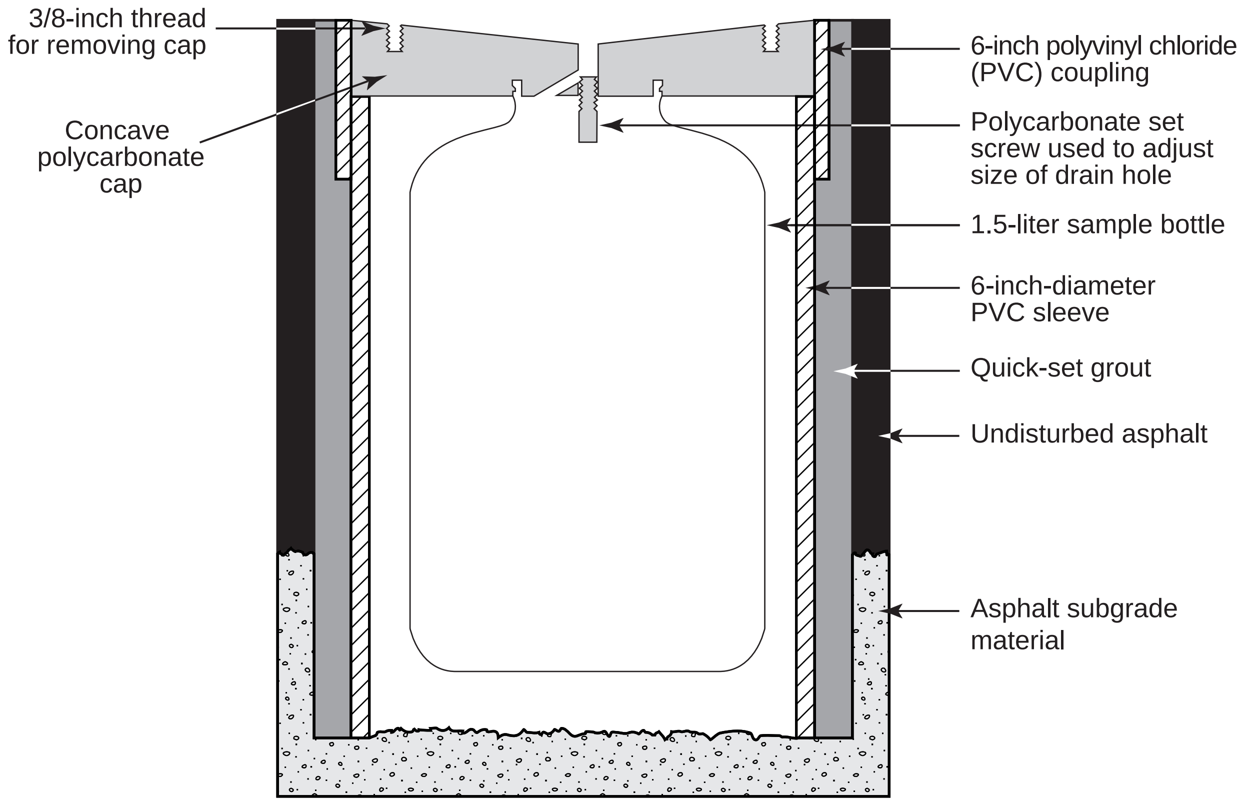

Figure 3. Diagram of street-runoff sampler.

drainage area of 138,823 acres (561.8 km^2) (Lathrop and others, 1992). Approximately 20 percent of the Lake Mendota drainage area is urban, 57 percent is agricultural, and the remaining 23 percent is grassland/woodland/marsh/open-water area (Betz and others, 1997). The Lakeland Basin is approximately 3 mi southeast of the Harper Basin.

In addition to the samples collected from source areas, a monitoring station was located at each basin storm-sewer outfall to collect flow-composite samples and to monitor discharge and rainfall. The total rainfall amounts for the months of June through October 1994 at Monroe and July through October 1995 at Harper were 9.24 and 10.67 in., respectively. These amounts are 64 percent and 71 percent of the average from 1961 to 1990 (Brian Hahn, National Weather Service, oral commun., 1997).

Acknowledgments

We thank all of the volunteers that allowed us to install our sampling equipment in their yards, the City of Madison Engineering Division and Department of Public Health for their efforts in making this study possible, Jeff Beck of the USGS for his exceptional field efforts, and Holly Ray and Dr. Bob Pitt at the University of Alabama at Birmingham for their work analyzing the street-dirt samples. Also, we thank Mary Anne Lowndes of the WDNR and Steve Corsi of the USGS for insightful comments that have greatly improved the report. Lastly, we thank Gail Moede and Aaron Konkol at the USGS for their help with the report editing and preparation of illustrations.

DATA-COLLECTION EQUIPMENT AND METHODS

Runoff samples were collected from each source area by use of sampling equipment slightly modified from that described by Bannerman and others (1993). Brief descriptions of the sampling equipment follow.

Street samplers. The street samplers were grouted into the street approximately 5 ft from the curb (fig. 3). The sample bottle was covered with a 6-in. concave polycarbonate cap, set flush with the street surface, with

a center drain hole. The bottle and cap were placed into a 6-in. diameter polyvinyl chloride (PVC) sleeve. Water flowed over the top of the cap and drained through the center hole into a collection bottle. The drain hole could be constricted by a set screw that controlled the flow rate into the sample bottle.

Driveway samplers. Runoff water from driveways was diverted into a sampler by means of a flat piece of clear plastic, 1/4 in. high by 1 in. wide by 3 ft long, glued to the surface of the driveway. The sampler consisted of a 1.5-L glass bottle placed in a 10-in.-diameter protective PVC sleeve set into the ground next to the driveway. A 1/2-in.-diameter silicon tube carried the runoff through a plastic cap covering the PVC sleeve and into the sampler. During the 1994 field season, the tubing emptied directly into the sample bottle, causing several sample bottles to overfill. To alleviate this problem, in 1995, the tube emptied onto a polycarbonate cap like those used with the street samplers, so that the volume of water entering the sample bottle could be controlled.

Lawn samplers. Lawn sample bottles received runoff through two 5-ft pieces of 1/2-in.-diameter PVC pipe placed flush with the surface of the ground, on a sloping surface, with an angle of about 150 degrees between the two pipes (fig. 4). Runoff entered the pipes through two slits cut the entire length of pipe. Each pipe was wrapped with fiberglass screen to prevent insects and large debris from entering. Wooden clothespins with small pieces of nylon rope held the pipes in place. Water from the pipes flowed into a sampler through a notched cap. The sampler was a 1-qt glass bottle placed in a 4-in.-diameter protective PVC sleeve. The cap had a notch to accommodate silicon tubing, which ran from the end of the PVC collector pipes to the sample bottle.

Roof samplers. Roof samplers were designed to divert a small portion of the water in the gutter downspout to a sample bottle. A 1/4-in.-diameter vinyl tube was attached to the inside of the downspout by means of plastic wire ties. Each tube went into a 1.5-L glass sample bottle that was placed in a covered 10-in.-diameter protective PVC sleeve. Because of problems with overfilled sample bottles, the design was changed in the same manner as the driveway samplers so that the volume of water entering the sample bottle could be controlled.

Parking-lot sampler. The parking-lot sampler collected runoff entering a storm-sewer inlet grate. A small portion of the inlet flow was diverted to a sample bottle by means of a 6-in. trough made of 1/2-in.-diameter PVC pipe cut length-wise and held in place with stainless steel hose clamps attached to the inlet grating. Water drained from the trough through a tube to a 2.5-gal glass sample bottle hanging from the inlet grate. No samples were collected from parking lots during 1995.

Basin storm-sewer outfall samplers. An automated sampling station was placed at the storm-sewer outfall of both the Monroe and Harper Basins. In 1994, water level in the basin storm-sewer outfall pipe was measured with a pressure transducer as water drained into a detention pond. Velocity was measured with an electromagnetic velocity meter. In 1995, stormwater-runoff volumes were computed using a modified Palmer-Bowlus flume design (Kilpatrick and others, 1985). The water level was measured one pipe diameter (36 in.) upstream from the entrance to the flume using a pressure transducer connected to a nitrogen bubble system. This water level was used in the following equation to calculate the total discharge through the flume:

$$Q = a[H_a/D]^b D^{2.5} ,$$

where

Q is discharge, in cubic feet per second,
a is a constant, 3.685,
b is a constant, 1.868,
H_a is the water level above the upstream lip of the flume, at a distance of one pipe diameter upstream from the flume entrance, in feet, and
D is pipe diameter, in feet.

Flow-composite water-quality samples were collected using programmable, refrigerated automatic samplers with 3/8-in.-diameter Teflon-lined sample tubing. Rainfall was measured using a tipping-bucket rain gage and was recorded by a digital data logger.

Stormwater-Sample Collection and Processing Protocols

Sample bottles were placed in the source-area samplers as close to the start of each rain event as possible. As the bottles were being deployed, the sampling equipment was rinsed with deionized water to remove any accumulated surface dirt. Before the lawn-sampler pipes were rinsed, they were cleaned with a small test-tube brush. As soon as possible after runoff had

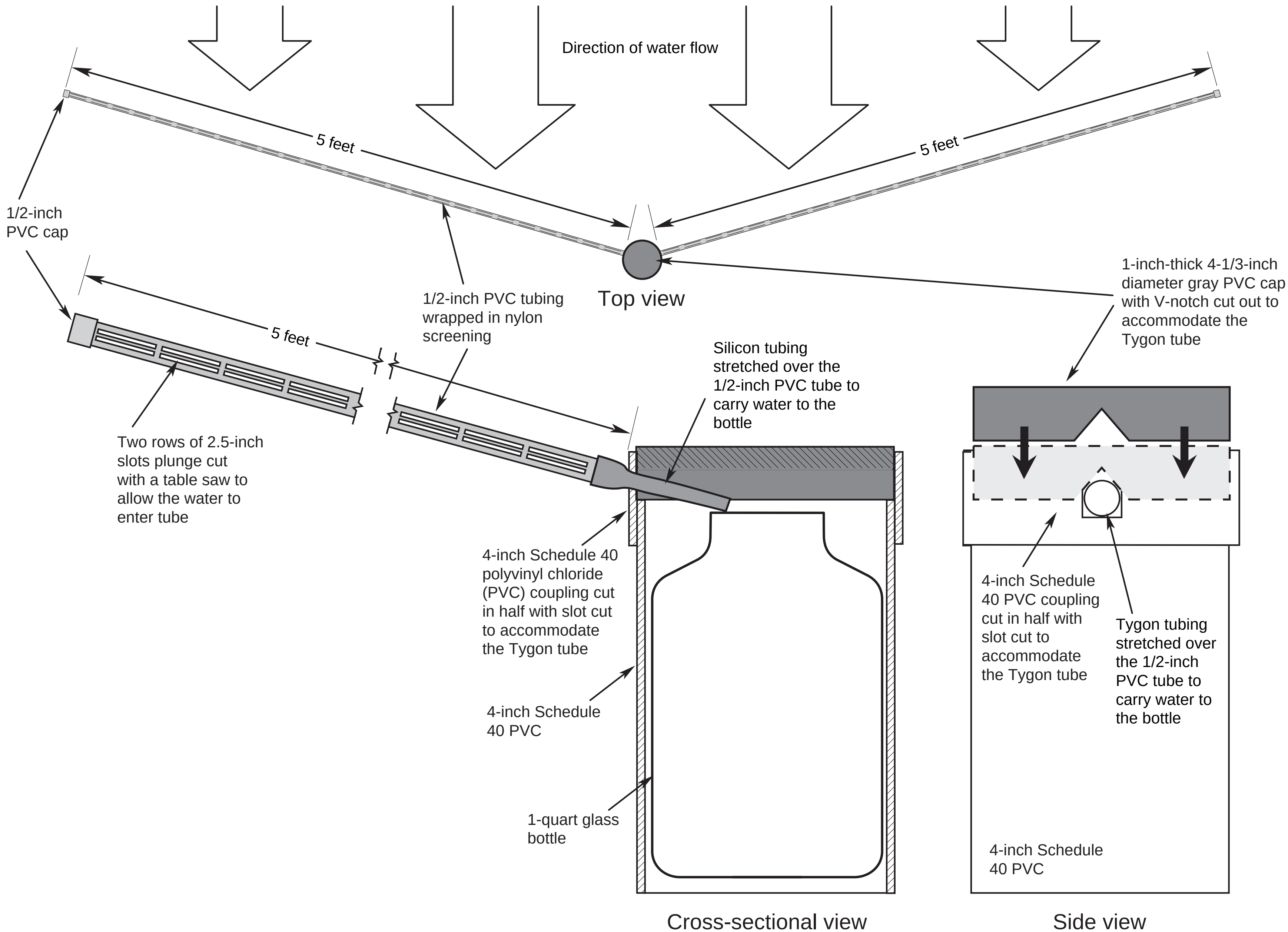

Figure 4. Diagram of lawn-runoff sampling equipment.

stopped, the sample bottles were collected and the approximate volume of water in each bottle was recorded.

All the bottles from a given source area were composited by pouring the water from each bottle into a 5-gal or 1-gal stainless steel, Teflon-coated churn splitter modified from the type described in Ward and Harr (1990). The City of Madison Department of Public Health Laboratory analyzed a small subsample taken from the churn for suspended solids and phosphorus.

Street-Dirt Collection and Analysis

In addition to stormwater-runoff samples, samples of street dirt were collected with a 9-gal wet-dry shop-vacuum using a 6-in.-wide wand. A section of the street was vacuumed from curb to curb, 10 times across each of 3 streets in the basin, similar to the technique described by Pitt (1979) and Bannerman (1983). Monroe Street, Glenway Street, and Seneca Place/Spring Trail/Huron Hill (the latter three are considered one residential street) were sampled during 1994 (fig. 2). Woodward Drive, Nova Way, and Luster Avenue were sampled during 1995. Woodward Drive did not have curbs, so the sample was collected by vacuuming between wooden 4-by 4-in. blocks placed at the edge of the asphalt on each side of the street. During the fall, leaves on the street would often plug the vacuum hose. To alleviate this problem, a 6-in. by 2-ft wooden frame was placed with the 6-in. side abutting the curb. Before vacuuming the inside of the frame, the leaves inside it were collected by hand and placed in the vacuum collection bag. Then the street was vacuumed in the normal manner.

The dirt samples were dried at 105°C, sieved into size fractions of >250 µm, 250-63 µm, 63-25 µm, and <25 µm and weighed. The sieved samples were sent to the University of Alabama at Birmingham (UAB) for phosphorus analysis. In addition to total phosphorus, samples collected from the Monroe Basin were analyzed for percentage of vegetative material. Two independent methods were used to determine the percentage of vegetative material: thermal chromatography and microscopic examination. In thermal chromatography, dirt samples were placed in ovens at increasing temperatures and the mass that was lost to incineration was determined after each increase in temperature. The mass loss was compared to the standard temperatures where various substances like leaves, rubber, and paper burned off. The sample mass lost at the temperature range corresponding to the leaf standards was assumed to be vegetation. In microscopic examination, samples of the dirt were compared to microscopic pictures of vegetation. More details of these methods can be found in Ray (1997).

SOURCES OF PHOSPHORUS

Measured Concentrations in Runoff from Source Areas

A total of 25 runoff events were monitored at each basin (tables A1 and A2). Runoff samples were collected from May to November of 1994 at Monroe and from June to November of 1995 at Harper and Lakeland. Driveway samples collected from the Monroe Basin were excluded because of problems with the sample bottle overfilling (discussed in the methods section). The individual event concentrations for suspended solids, total phosphorus, and dissolved phosphorus at Monroe and Harper Basins are listed in appendix tables A3–A8. Summary statistics are listed in table 2. Concentrations of these constituents from the Lakeland Basin are listed in appendix table A9.

The concentration data from the Monroe and Harper Basins seem to exhibit log-normal distributions that are consistent with urban-runoff concentration data collected during the Nationwide Urban Runoff Project (U.S. Environmental Protection Agency, 1983). In such cases, the geometric mean is a better estimate of the central tendency than the arithmetic mean because the geometric mean gives less weight to extremes (Helsel, 1992). Several of the coefficients of variation in table 2 have a value greater than 1, indicating substantial variability in concentrations within a source area.

The large variation seen in the source-area concentration data could cast doubt on the predictability of the data. For lawn runoff, the difference between geometric mean phosphorus concentrations from 1994 to 1995 was greater than a factor of 2; however, the lawn-runoff data collected from the Lakeland Basin are remarkably similar to data collected at Harper (table 3), indicating that the variation in lawn-runoff phosphorus concentrations is not random. Primary sources of phosphorus, such as tree canopy, also could have a large effect on the source-area concentrations measured between basins. Figure 5 illustrates a trend between the concentration of phosphorus and the percentage of overhead tree canopy

Table 2. Concentrations for suspended solids, total phosphorus, and dissolved phosphorus at the Monroe Basin and Harper Basin, 1994–95

[--, concentrations were not used because of problems with the samplers; -, source area not present in basin; mg/L, milligrams per liter]

Statistic	Source area							
	Lawns	Feeder street	Collector street	Arterial street	Driveways	Parking lots	Pitched roofs	Flat roofs
	MONROE BASIN							
	Suspended solids (mg/L)							
Geometric mean	59	68	51	65	--	51	15	18
Coeff. of variation	.55	1.17	.97	.92	--	1.27	.95	1.21
Mean	85	99	67	83	--	82	85	35
Median	75	60	46	64	--	44	18	20
	Total phosphorus (mg/L)							
Geometric mean	0.79	0.40	0.22	0.18	--	0.10	0.07	0.13
Coeff. of variation	.62	1.24	1.23	1.15	--	1.04	.76	.96
Mean	1.03	.75	.36	.24	--	.14	.09	.2
Median	.99	.31	.16	.17	--	.09	.06	.12
	Dissolved phosphorus (mg/L)							
Geometric mean	0.37	0.16	0.05	0.03	--	0.02	0.02	0.02
Coeff. of variation	.62	1.72	1.47	1.20	--	1.24	1.22	1.24
Mean	.52	.40	.14	.05	--	.04	.03	.04
Median	.61	.14	.04	.03	--	.02	.02	.02
	HARPER BASIN							
	Suspended solids (mg/L)							
Geometric mean	122	69	-	-	34	-	17	-
Coeff. of variation	.37	.68	-	-	.93	-	.96	-
Mean	132	98	-	-	57	-	25	-
Median	154	88	-	-	31	-	17	-
	Total phosphorus (mg/L)							
Geometric mean	1.61	0.24	-	-	0.18	-	0.15	-
Coeff. of variation	1.12	.75	-	-	.80	-	.68	-
Mean	2.34	.31	-	-	.24	-	.19	-
Median	1.54	.22	-	-	.20	-	.15	-
	Dissolved phosphorus (mg/L)							
Geometric mean	0.77	0.08	-	-	0.07	-	0.08	-
Coeff. of variation	1.51	.98	-	-	1.0	-	.83	-
Mean	1.54	.12	-	-	.11	-	.11	-
Median	.81	.08	-	-	.07		.07	-

Table 3. Rainfall amounts and intensities and total-phosphorus concentrations from lawn-runoff samples for Harper and Lakeland Basins, Madison, Wis., 1995
[in/hr, inches per hour; mg/L, milligrams per liter]

	HARPER			LAKELAND		
Start of rain event (date)	Rainfall (inches)	Intensity (in/hr)	Total-phosphorus concentration (mg/L)	Rainfall (inches)	Intensity (in/hr)	Total-phosphorus concentration (mg/L)
06/26/95	0.26	0.12	10.72	0.31	0.17	9.05
07/05/95	.36	.62	1.32	.10	.16	2.06
07/15/95	.50	.12	3.61	.80	.10	2.99
07/22/95	.79	.10	1.08	.80	.09	1.35
08/16/95	.61	.43	1.82	.55	.94	2.48
08/16/95	.38	.29	.60	.55	.49	.58
08/28/95	.80	.19	1.39	.67	.15	1.58
10/19/95	.32	.07	2.24	.33	.06	2.59

on streets for the Monroe and Harper Basins. Canopy in the Monroe Basin tends to be less than 35 percent, whereas the percentage of canopy in the Harper Basin ranges from 5 to 78 percent. The percentages of overhead tree canopy for all streets in the study are listed in appendix table A18. Variation also could be caused by meteorological factors like rain depth, intensity, or inter-event period or by seasonal variables.

Roof runoff had the lowest geometric mean concentrations of suspended solids, and lawn runoff had the highest total and dissolved phosphorus concentrations in both the Monroe and Harper Basins (figs. 6 and 7). In addition, patterns in geometric mean concentrations between source areas within each basin were similar; however, their magnitudes were very different. The geometric mean concentration of phosphorus for low-traffic streets in the Monroe Basin were about twice those at the Harper Basin. Conversely, geometric mean phosphorus concentrations for lawn and roof runoff in the Harper Basin were more than twice as high as those in the Monroe Basin. The beginning of the sampling periods differed by one month between basins (Monroe Basin in May and Harper Basin in June), and this difference may have caused some of the variability.

Concentration results for suspended solids and phosphorus from earlier source-area studies in Madison, Wis., Marquette, Mich., and Birmingham, Ala. (Bannerman and others, 1993; Steuer and others, 1997; Pitt and others, 1995), were compared to the concentration results from this study. Suspended-solids concentrations in street-runoff samples collected during the other studies were considerably higher than those in samples collected for this study. Sandier soils are present in Marquette that could partially account for this difference. Furthermore, some of the same lawns in the Monroe Basin were monitored for phosphorus concentrations in the previous Madison study (Bannerman and others, 1993), and both the dissolved and total phosphorus geometric means calculated for that study were more than three times higher than those in 1994. Because phosphorus concentrations varied highly from Monroe and Harper Basins, did not closely agree with each other, and did not agree well with previous studies, the geometric mean of the combined data collected at Monroe and Harper Basins was used for the modeling phase of this study.

Calibration of the Source Loading and Management Model (SLAMM)

A concentration data base to simulate stormwater quality and theoretical runoff coefficients to simulate runoff volumes is used in the Source Loading and Management Model (SLAMM). Because large amounts of concentration data and runoff information were collected during this study, it was an opportunity to calibrate the model's concentration data base and improve the runoff coefficients with data collected from the Monroe and Harper Basins.

Calibrating SLAMM with concentration and water-volume data was a three-step process. First, the runoff volume generated by each source area was calibrated (a critical step because an accurate water volume

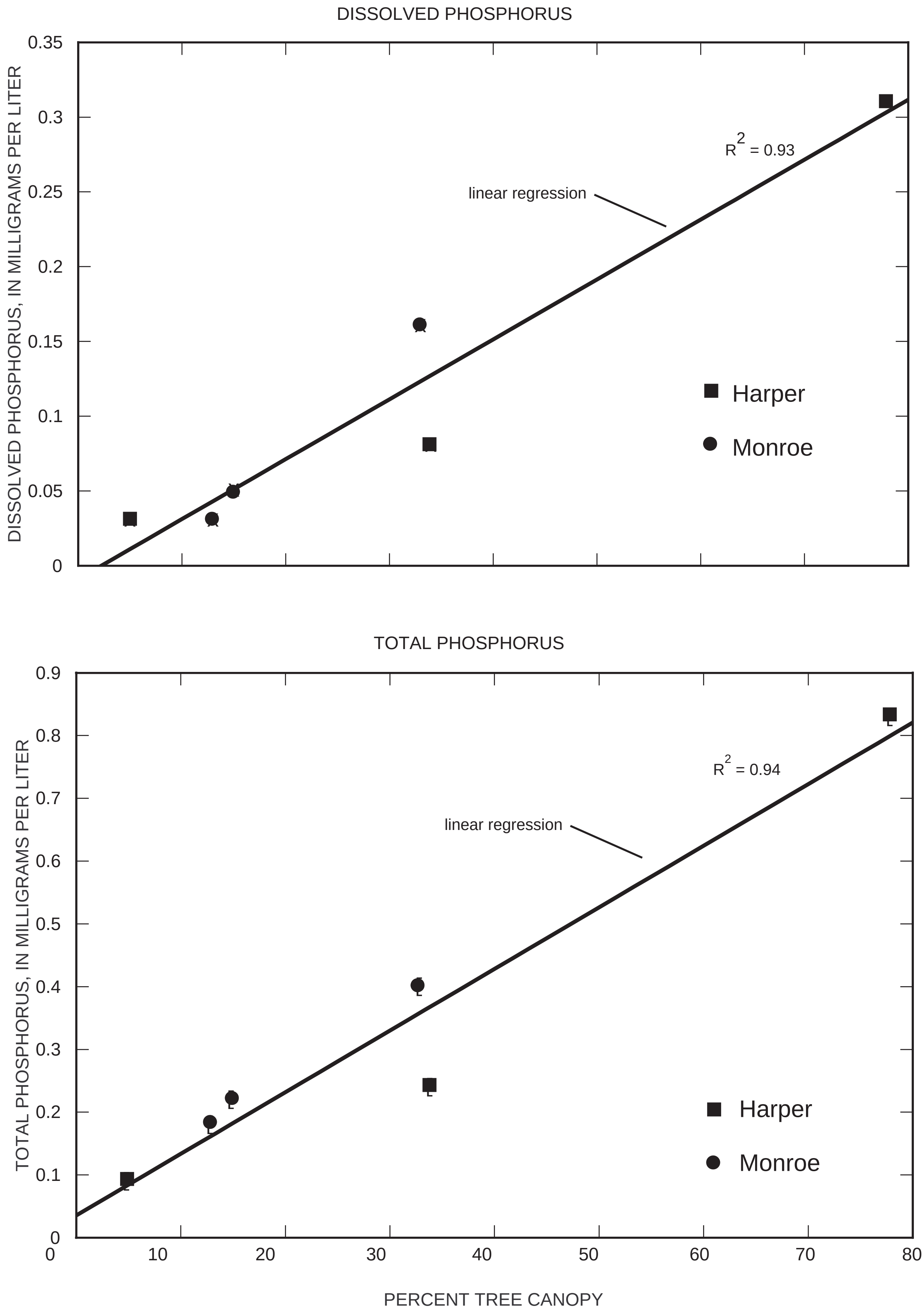

Figure 5. Relations between overhead tree canopy and phosphorus concentrations in street-runoff samples, Harper and Monroe Basins, Madison, Wis. (R^2 = coefficient of determination)

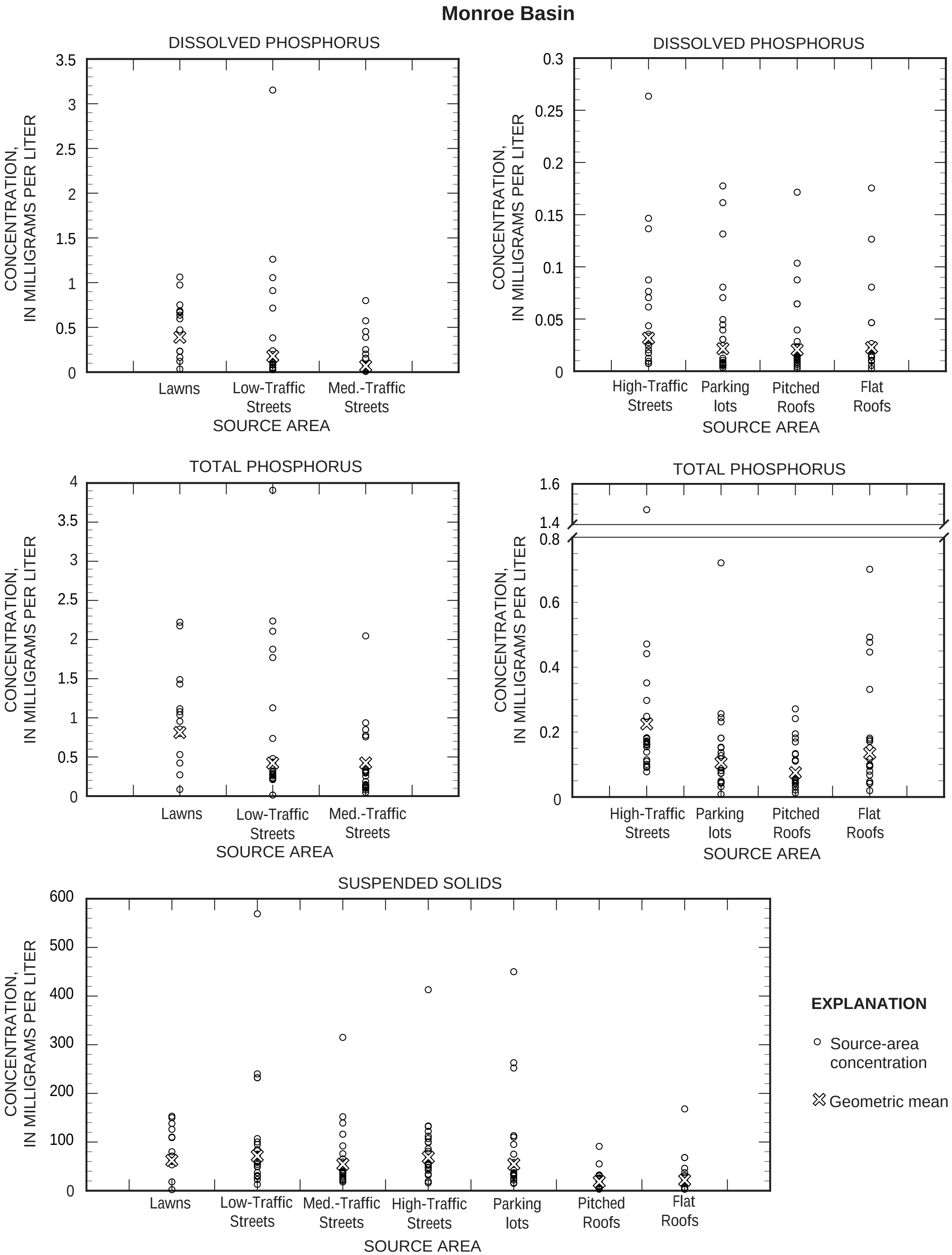

Figure 6. Phosphorus and suspended-solids concentrations from source areas in the Monroe Basin, Madison, Wis.

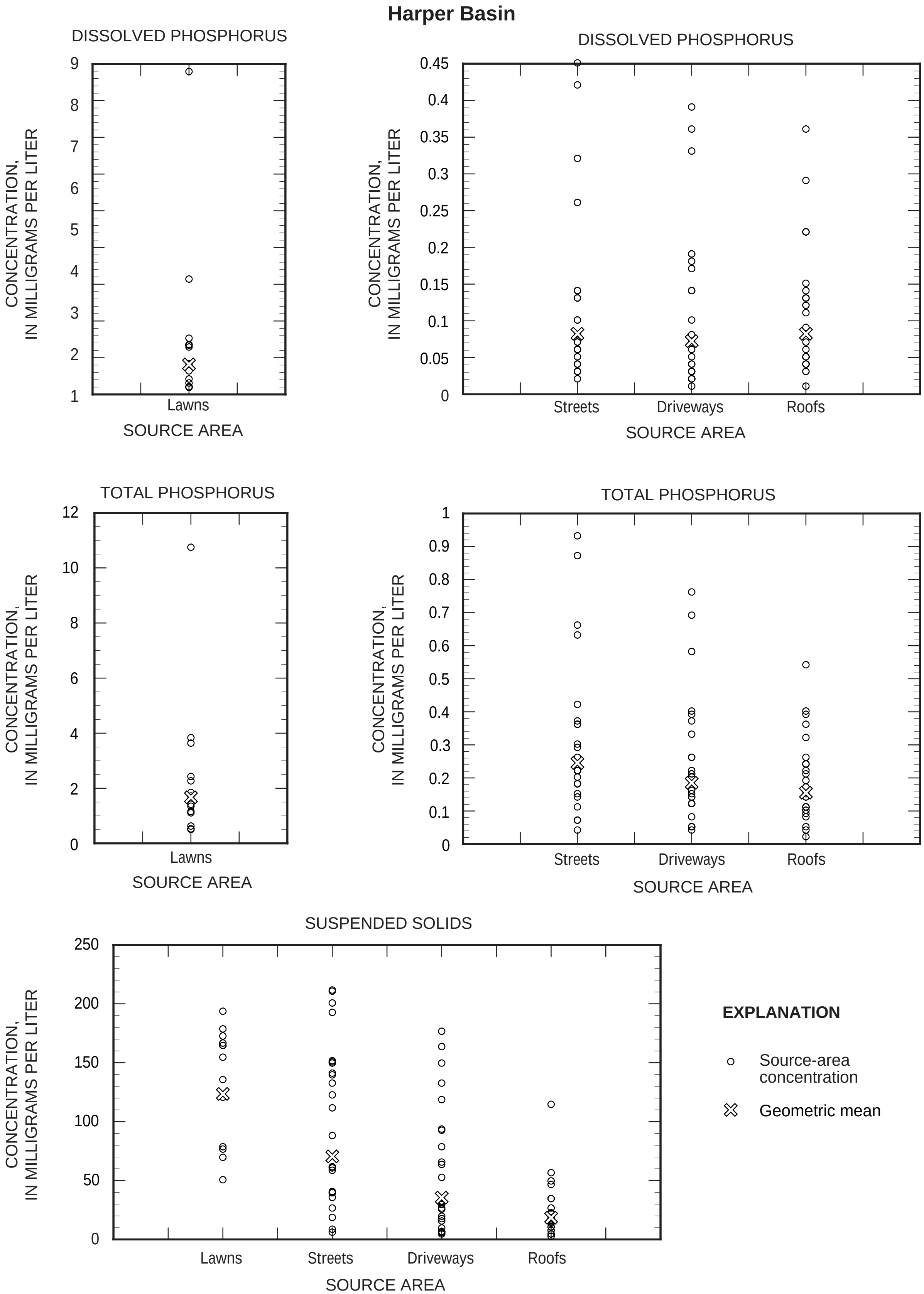

Figure 7. Phosphorus and suspended-solids concentrations from source areas in the Harper Basin, Madison, Wis.

is essential for estimating all pollutant loads). Second, sediment was calibrated because sediment concentrations and loads are used in SLAMM to estimate phosphorus loads. The final step was to calibrate the model for phosphorus concentrations. The description of each basin data file used in SLAMM is given in appendix B.

A systematic procedure was used to calibrate suspended-solids and phosphorus concentrations in SLAMM. First, a mass-balance approach compared total measured loads from source areas summed over 25 events to the loads measured at the outfall. Monitored loads from source areas were calculated using SLAMM-generated water volumes. Individual source areas were not equipped to measure runoff volumes during an event. Therefore, the accuracy of source-area volumes, as assigned by SLAMM, was subject to agreement with the actual volumes measured at the outfall. If the sum of all source-area volumes closely matched what was measured at the outfall, the individual source-area volumes assigned by SLAMM were assumed to be correct. Second, source-area concentrations were adjusted to optimize the mass balance. SLAMM was adjusted after agreement between measured source-area and outfall loads was achieved.

Water-Volume Calibration

Water-runoff volume from each source area for each rain event is calculated with the model. These calculations are based on the amount of rainfall and a runoff coefficient developed for various rainfall depths for each source area. Source-area characteristics such as imperviousness, connectedness (amount of impervious area directly connected to the storm sewer), and infiltration rates on pervious areas were used to develop runoff coefficients (Pitt, 1987). The volumetric discharges for each source area are then summed for each event. The total runoff volume can be decreased in the model by using control measures, such as infiltration devices.

SLAMM was used to estimate runoff volume for the 25 storm events from all source areas in each basin. The sum of the volumes from all of these source areas was compared to the volume measured at the basin storm-sewer outfalls for these 25 events. Initially, the model overpredicted the water volumes measured at Monroe by a total of 55 percent (over the entire study period), whereas it underpredicted those measured at Harper by only 2 percent. To obtain a balance of overprediction and underprediction between the basins, the runoff coefficients were adjusted. Historically, more measurements have been made for runoff from impervious surfaces (Pitt, 1987) and more than 50 percent of the area within each basin is pervious, mostly because of residential lawns. Therefore, it was decided that the runoff coefficients for pervious areas were more uncertain and model calibration could benefit from minor adjustments.

Two sets of runoff coefficients are available for pervious areas; one is designed to represent clayey soils, and the other represents sandy soils. The predicted water volumes mentioned above were determined using the runoff coefficients for clayey soils (based on soil maps). Changing the pervious classification from clayey to sandy resulted in SLAMM underprediction of water volumes; approximately a 4 percent and a 42 percent underprediction at the Monroe and Harper Basin storm-sewer outfalls, respectively. A much better agreement was achieved at Monroe by assuming that the original soil classification was incorrect. Sandy and clayey runoff coefficients, available to the model, probably represented two extremes, and more realistic runoff coefficients fell somewhere between these two coefficients.

Lawn-runoff data collected from Monroe and Harper Basins were used to create runoff coefficients that more accurately represent the pervious conditions found in Madison. First, the rainfall depth sufficient to initiate runoff in SLAMM was changed using data on the amount of stormwater in the lawn-sample bottles after each event. For rainfall amounts less than approximately 0.3 in., the bottles were less than 10 percent filled. From this observation, 0.3 in. was established as the minimum precipitation required to initiate runoff. However, the runoff coefficient table for clayey soils used in SLAMM resulted in 10 percent runoff for a rainfall depth of 0.2 in. Hence, SLAMM was changed to initiate runoff at 0.3 in. rather than 0.2 in. of precipitation.

In addition to the change described above, a trial-and-error approach was used to change the coefficients until optimum agreement was reached between water volumes predicted in SLAMM and those measured at the Monroe and Harper storm-sewer outfalls. The resulting coefficients were between those for sandy and clayey soils and were approximately two-thirds the value for clayey soils. Figure 8 shows how the new “Madison” runoff coefficients compare to the sandy and clayey coefficients.

Based on the revised Madison runoff coefficients, SLAMM overpredicted storm-sewer outfall volumes at Monroe by 23 percent and underpredicted Harper

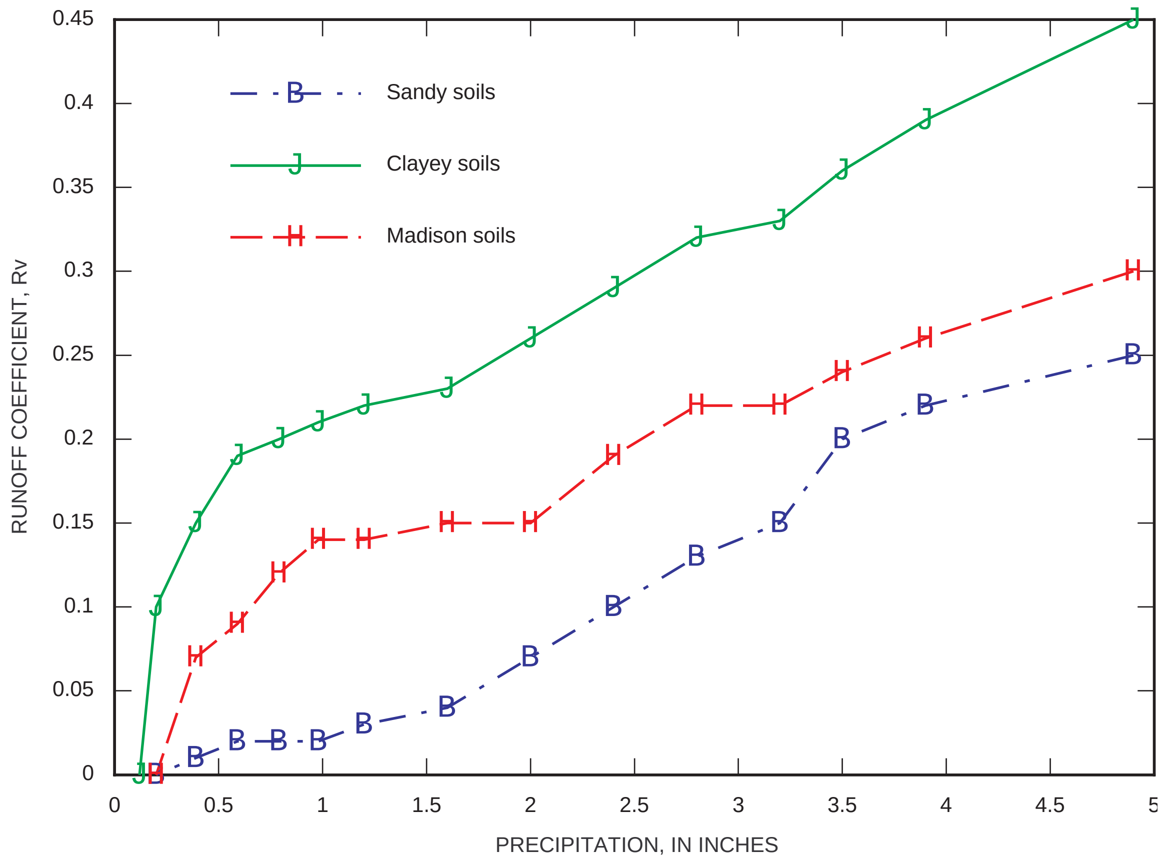

Figure 8. Lawn-runoff coefficients used for SLAMM-calculated volumes for basins in Madison, Wis. (Soil runoff coefficients for Madison are between those for sandy and clayey soils and are approximately two-thirds the value of clayey soils.)

storm-sewer outfall volumes by 24 percent (table 4). Event-by-event comparisons are listed in appendix tables A10 and A11. The Madison coefficients also produced consistent lawn-runoff contributions in both basins, approximately 20 percent of the total volume. It is expected that the percentage of lawn contribution would be similar for both basins because they have nearly the same percentage of lawn area.

Table 4. Percentage difference in cumulative modeled water volumes compared with measured outfall water volumes using three soil types, Madison, Wis.
[%, percent]

Basin	Sandy soils (%)	Clayey soils (%)	Madison soils (%)
Monroe	-4	55	23
Harper	-42	-2	-24

Sediment Calibration

Once the runoff volumes were calibrated, SLAMM was used to estimate sediment loads for the 25 events in each basin. With the exception of streets, a data base of sediment concentrations for each source area is used in SLAMM and these concentrations are applied to the water volumes to derive a load. Sediment concentrations from streets are computed by a wash-off function that is related to a street-dirt accumulation rate.

A mass-balance approach was used to test the source-area concentrations within each basin with those measured at the storm-sewer outfall. Source-area loads were computed by multiplying the water volumes produced from SLAMM by the concentrations measured at the source areas for each event and then summing these event loads. Sidewalks and woodlots were two of the larger unmonitored source areas in each basin, accounting for 12 percent and 1 percent of the water volume produced at Monroe and 7 percent and 2 percent at Harper, respectively. To add sidewalks to the load estimates, concentrations measured at driveways were applied to estimates at sidewalks to create a sidewalk load. Woodlot concentrations were estimated by use of data collected in an undeveloped urban site near Supe-

rior, Wis. (Steuer and others, 1997). The source-area loads were 39 percent lower and 60 percent lower than the measured load at the storm-sewer outfall in the Monroe and Harper Basins, respectively. This difference between source-area and storm-sewer outfall loads indicates that one or more source areas within each basin were not effectively monitored.

Streets were the most likely source area to be ineffectively monitored. Street samplers were placed approximately 5 ft away from the curb to prevent gutter flow into the sampler because gutter flow usually contains a mixture of water from several source areas. Other street studies (Pitt, 1979) have estimated that 90 percent of the dirt on residential streets in good condition with little to no parking accumulates within 3 ft of the curb. A larger amount of dirt can sometimes collect along the curb itself rather than in the driving lane. Some of this dirt could have been deposited on the driving lane, and turbulence from passing vehicles and wind may have moved it to the curb. Most street dirt falls within 1 to 2 ft of the curb if the driving lane is next to the curb (Pitt, 1979). This information suggests that the street samplers in the Monroe and Harper Basins were too far from the curb (5 ft) to representatively collect the particulate dirt from the streets.

For the reasons previously described, a trial-and-error approach was used to select a street-sediment concentration that more accurately reflected the street sediment entering the storm sewer. The final suspended-solids concentrations for streets were increased by a factor of 5. Applying this factor to the simulated street suspended-solids concentration during each storm event allowed the sum of source-area loads to be within 7 percent and 9 percent of the storm-sewer outfall loads at Monroe and Harper, respectively (table 5). The geometric means for the revised street suspended-solids concentrations were 340 and 325 mg/L for low- and high-traffic streets, respectively. These values were within 5 percent of those measured at both Marquette, Mich. (Steuer and others, 1997), and Madison, Wis. (Bannerman and others, 1993).

The geometric means of the observed suspended-solids concentrations, excluding streets, for the 25 storm events at Monroe and Harper Basins were placed into the SLAMM data base (table 6). These values tend to be smaller than those used in previous SLAMM calibrations (appendix table B2). The suspended-solids concentrations for streets were not as easily altered because they are determined by dirt accumulation and wash-off functions in the model. Entering the geometric means enabled the model to more accurately predict the loads measured at the storm-sewer outfall. After summing the 25 events, sediment loads predicted by SLAMM were 17 percent lower at Monroe and 32 percent lower at Harper compared to the measured storm-sewer outfall loads.

Table 5. Percentage difference in cumulative source-area sediment loads, before and after sediment adjustment, and modeled and measured sediment loads at the basin outfall, Madison, Wis.

[Loads computed as suspended solids; %, percent]

Basin	Cumulative source area compared with storm-sewer outfall		Modeled compared with measured (%)
	Suspended solids before adjustment (%)	Suspended solids after adjustment (%)	
Monroe	-39	-7	-4
Harper	-60	-9	-17

Table 6. Suspended-solids concentrations used to calibrate the Source Loading and Management Model for basins in Madison, Wis.

[mg/L, milligrams per liter; --, a series of algorithms and coefficients are used in the model to calculate a suspended-solids concentration for street runoff]

Source area	Suspended solids (mg/L)	
	Residential	Commercial
Driveways	34	34
Lawns	84	84
Parking lots	51	51
Streets	--	--
Woodlots	15	15
Roofs	16	18
Sidewalks	34	34

To improve the match between measured and simulated storm-sewer outfall loads, the delivery coefficients were removed from SLAMM calculations, essentially assuming 100-percent delivery from source area to storm-sewer outfall. The delivery coefficients had been added in a previous calibration study to force a match to the storm-sewer outfall numbers. This adjustment resulted in a 4 percent and 17 percent under-simulation between storm-sewer outfall loads of suspended solids calculated by SLAMM and those measured at the storm-sewer outfall for Monroe and Harper, respectively (table 5). Event-by-event comparisons are listed in appendix tables A12 and A13.

Phosphorus Calibration

One objective in calibrating phosphorus concentrations in SLAMM was to ensure that the Monroe and Harper Basins were accurately represented by the monitored source areas. The sum of source-area loads for total phosphorus for the 25 storm events was nearly identical to the storm-sewer outfall load (table 7). The difference was larger for dissolved phosphorus, but no information was available to determine what adjustments should have been made to reduce the difference. For this reason, the unadjusted concentrations were entered into the SLAMM data base.

Table 7. Percentage difference between cumulative source area versus outfall loads and modeled results versus outfall loads, after calibration of the Source Loading and Management Model for basins in Madison, Wis.
[%, percent]

Basin	Cumulative source area versus storm-sewer outfall		Model results after calibration versus storm-sewer outfall	
	Phosphorus load			
	Dissolved (%)	Total (%)	Dissolved (%)	Total (%)
Monroe	39	-1	-9	-24
Harper	35	4	-10	-28

The model simulates total phosphorus loads by adding the dissolved phosphorus and particulate phosphorus loads. For all source areas except streets, particulate-phosphorus concentrations were calculated using total- and dissolved-phosphorus and sediment concentrations measured at the Monroe and Harper Basins. To be consistent with calibration procedures, particulate-phosphorus concentration for street runoff was calculated using the adjusted value for sediment (an increase by a factor of 5). Changing the phosphorus concentrations resulted in SLAMM undersimulation of dissolved and total phosphorus by 9 percent and 24 percent at the Monroe storm-sewer outfall and 10 percent and 28 percent at the Harper storm-sewer outfall, respectively. Event-by-event comparisons are listed in appendix tables A14-A17.

The dissolved- and particulate-phosphorus concentrations entered into the SLAMM data base are listed in tables 8 and 9. These phosphorus concentrations can be compared to those originally in SLAMM (before Madison data were incorporated), which are listed in appendix table B2. Significant changes in dissolved-phosphorus concentrations (table 8) were observed for lawns (from 0.22 to 0.53 mg/L), streets (from 0.39 to 0.12 mg/L), woodlots (from 0.25 to 0.01 mg/L), and sidewalks (from 0.60 to 0.07 mg/L). With the exception of streets, where the particulate-phosphorus concentrations in runoff decreased, particulate-phosphorus concentrations increased significantly (table 9).

Table 8. Dissolved-phosphorus concentrations used to calibrate the Source Loading and Management Model for basins in Madison, Wis.
[mg/L, milligrams per liter]

Source-area	Dissolved phosphorus (mg/L) Residential	Dissolved phosphorus (mg/L) Commercial
Driveways	0.07	0.07
Lawns	.53	.53
Parking lots	.02	.02
Streets	.12	.03
Woodlots	.01	.01
Roofs	.04	.02
Sidewalks	.07	.07

Table 9. Particulate-phosphorus concentrations used to calibrate the Source Loading and Management Model for basins in Madison, Wis.
[mg/L, milligrams per liter]

Source area	Particulate phosphorus (mg/L) Residential	Particulate phosphorus (mg/L) Commercial
Driveways	2,649	2,649
Lawns	4,943	4,943
Parking lots	1,467	1,467
Streets	569	409
Woodlots	5,000	5,000
Roofs	3,777	7,946
Sidewalks	2,649	2,649

Distribution of Source-Area Loads

The distribution of suspended-solids and total- and dissolved-phosphorus loads for source areas in the Monroe and Harper Basins using measured source-area concentrations multiplied by SLAMM-generated water volumes is shown in table 10. The distribution of water volumes is nearly identical at Monroe and Harper Basins. The percentage of the total basin represented by each source area is similar for both basins (table 1); thus, one should expect to see similar relative volumes of water calculated from both basins. Streets contributed most of the suspended-solids loads at both Monroe

and Harper Basins, generating 81 percent and 73 percent, respectively. Lawns contributed more than 10 percent of the solids loads at both basins. The phosphorus loading, however, was quite different. Lawns in the Harper Basin generate more than two-thirds of the phosphorus loads, whereas phosphorus in the Monroe Basin is more evenly distributed between lawns and streets. These differences in load distribution are the result of the measured phosphorus concentrations, especially for lawns, which are much higher for the Harper Basin (table 2).

The suspended-solids load distribution at the Monroe Basin in 1994 is similar to the distribution observed in a 1991 study (Bannerman and others, 1993). Streets contributed 80 percent of the total basin suspended-solids load in 1991 and 81 percent in 1994. Lawns also were comparable, contributing 7 percent and 10 percent of the total basin suspended-solids load in 1991 and 1994, respectively. Total and dissolved phosphorus, however, were very different. During the 1991 study, the proportion of the total-phosphorus load from streets (58 percent) outweighed that for lawns (14 percent). The same was true in 1991 for dissolved phosphorus, where streets produced 46 percent and lawns 22 percent of the basin load. However, most total- and dissolved-phosphorus loading in 1994 was attributed to lawns rather than streets. Streets and lawns, in 1994, generated 37 and 44 percent of the total-phosphorus load and 39 and 45 percent of the dissolved-phosphorus load in the Monroe Basin. The difference in distributions between the two studies is possibly due to differences in sampling methodology. The street-sampler design was modified for the 1994 study to eliminate a first-flush effect, where the sample bottle would quickly fill with stormwater and act as a sediment trap for the remaining duration of the storm event. Also, during the 1994 study, 25 events were monitored, whereas only 10 events were monitored in 1991. This larger sample size in 1994 improves confidence in the loading-distribution estimates.

Distribution of suspended-solids, total-phosphorus, and dissolved-phosphorus loads estimated by SLAMM are given in table 11. The distribution of loads is consistent with the distribution of measured loads shown in table 10. For each constituent, slightly less total load was simulated with SLAMM than calculated using the measured concentrations (other than suspended solids from streets), yet the distributions of each constituent were similar. Streets and lawns contribute nearly all of the suspended-solids load for the entire basin. Streets alone contribute more than 75 percent of the suspended solids at both Monroe and Harper Basins. Additionally, the significance of lawns as generators of phosphorus is again noted in SLAMM simulations. Lawns in the Harper Basin contribute 52 and 61 percent of total and dissolved phosphorus loads, and lawns in the Monroe Basin contribute 49 and 57 percent. Streets contribute the second largest phosphorus loads (about 25 percent), whereas driveways and sidewalks combined contribute approximately 10 percent.

The distribution of suspended solids and total and dissolved phosphorus for source areas in the Monroe and Harper Basins using measured source-area concentrations multiplied by SLAMM-generated water volumes is shown in table 12. Only loads for the source areas measured are shown in table 12; concentrations of suspended solids in street runoff have not been adjusted. These source areas accounted for 82 and 90 percent of the total water volume from the Monroe and Harper Basins, respectively.

The suspended-solids distributions shown in table 12 differ from tables 10 and 11, in that the significance of lawns as a source increases and the significance of streets as a source decreases. Streets are still the largest source of suspended solids in both basins. The phosphorus distributions also change, but not as much as the suspended solids because the measured phosphorus concentrations were used in all three tables (tables 10, 11, and 12). The significance of lawns as a source increases slightly, and streets are a slightly larger source in some cases, and in others, are slightly smaller sources. Results shown in table 12 indicate that the adjustments made to suspended-solids concentrations in street runoff do not greatly affect the phosphorus distributions in the basins.

Sediment and Phosphorus Mass in Street-Dirt Samples

Approximately 75 percent of the total sediment mass in the street-dirt samples originated in the >250 μm size fraction, whereas the smaller fractions (<63 μm) made up less than 5 percent. Material composed of leaves, twigs, and other organic debris also were measured, contributing, on average, less than 10 percent of the total sediment mass of the sample (fig. 9). Total sediment mass data for street-runoff samples is given in the appendix tables A19 and A20.

Table 10. Distribution of loads based on measured values at Monroe and Harper Basins, Madison, Wis., and incorporating the suspended-solids adjustment

[N/A, source area not present; %, percent abundance; --, value less than 0.5 percent]

Source area	HARPER				MONROE			
	Water volume[1] (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)	Water volume (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)
Lawns	21	15	67	71	20	10	44	45
Streets	37	[2]73	14	11	38	[2]81	37	39
Driveways	18	7	9	9	12	2	5	4
Sidewalks	7	3	4	3	14	3	5	4
Parking lots	3	1	1	--	6	2	1	1
Roofs	11	1	3	4	7	--	1	--
Parks	1	--	2	2	3	2	7	7
Woodlots	3	--	--	--	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	N/A	1	--	--	--
Total	311,122	3,598	9	5	2,417,341	26,045	70	33

[1]Water volume totals expressed in cubic feet; all other totals expressed in pounds.

[2]Street-runoff concentrations multiplied by 5.

Table 11. Distribution of loads from model simulation results at Monroe and Harper Basins, Madison, Wis.

[N/A, source area not present; %, percent abundance; --, value less than 0.5 percent]

Source area	HARPER				MONROE			
	Water volume[1] (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)	Water volume (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)
Lawns	21	11	52	61	20	12	49	57
Streets	37	81	32	24	38	77	26	22
Driveways	18	4	8	7	12	3	5	4
Sidewalks	7	1	3	3	14	3	6	5
Parking lots	3	1	1	-	6	2	1	1
Roofs	11	1	3	2	7	1	2	--
Parks	1	--	2	2	3	2	8	9
Woodlots	3	--	1	--	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	N/A	1	1	2	2
Total	311,122	3,170	7	4	2,417,341	20,814	60	29

[1]Water volume totals expressed in cubic feet; all other totals expressed in pounds.

Table 12. Distribution of loads from monitored source areas only, based on unadjusted concentrations at the Monroe and Harper Basins, Madison, Wis.

[%, percent abundance; percentage columns may not add up to 100% because of independent rounding]

Source area	HARPER				MONROE			
	Water volume (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)	Water volume (%)	Suspended solids (%)	Total phosphorus (%)	Dissolved phosphorus (%)
Lawns	23	41	70	75	24	28	56	69
Streets	41	43	20	15	46	53	33	21
Driveways	20	10	7	6	14	9	7	8
Parking lots	4	3	1	0	7	7	2	1
Roofs	12	3	3	4	9	3	2	1

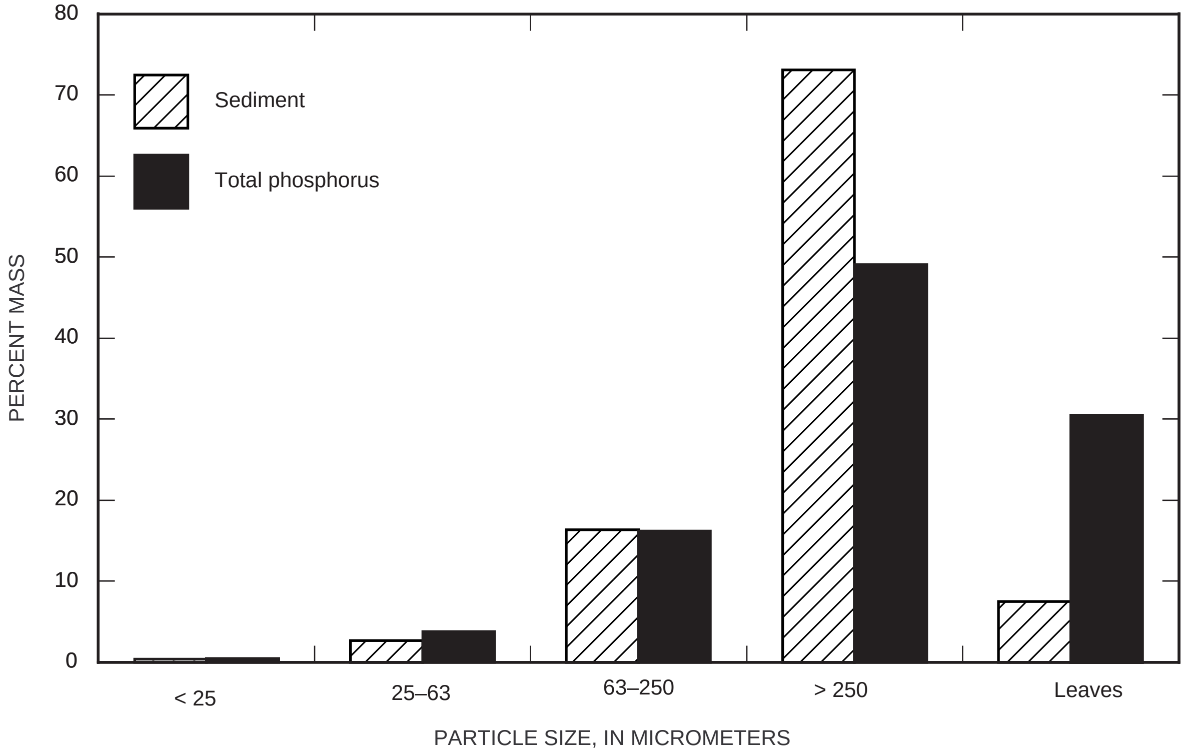

Figure 9. Relations between sediment and total-phosphorus mass from street-dirt samples for five particle-size fractions for basins in Madison, Wis.

Like sediment mass, the largest amount of total phosphorus was found in the >250 µm size fraction (nearly 50 percent) (fig. 9). Combining this size fraction with the leaf fraction, about 80 percent of the total phosphorus is accounted for. The contribution of total phosphorus mass decreased as the size fraction decreased. Other studies have shown that large phosphorus concentrations correspond with small particle sizes because of the high surface area to mass ratio for small particles (Boyd and Sartor, 1972). However, the bulk of the phosphorus load results from the greater particle-size fractions (Ray, 1997). Approximately 25 percent of the total phosphorus mass in each size fraction can be attributed to leaves (Ray, 1997). Phosphorus data for street-dirt samples can be found in the appendix tables A21 and A22.

A recent study of particle-size distribution in stormwater at the Monroe storm-sewer outfall demonstrated that most of the solids are in the particle sizes <63 µm (Greb and Bannerman, 1997). This distribution is the opposite of the particle-size distribution observed for the street dirt collected in this study. These results indicate either a loss of the larger particles somewhere between the street and the outfall or a problem in collecting larger particles in the runoff samples. Most of the larger particles (>63 µm) might settle out before reaching the storm-sewer outfall. Street sweeping, resuspension onto street terraces, and catch basins can remove these particles from the streets before they reach the storm sewer. Also, the transport of large particles in a storm sewer is not as efficient as the transport of smaller, more mobile particles. Large sediment particles may become trapped or part of the bedload before reaching the sampler. Bedload is not sampled efficiently by the automatic samplers described earlier in this report.

SUMMARY AND CONCLUSIONS

Concentrations of suspended solids, total phosphorus, and dissolved phosphorus were collected from various source areas at two urban residential basins in Madison, Wis. To represent a range of source-area concentrations for urban residential basins in Madison, the geometric means of the combined concentration data from the Monroe and Harper Basins were incorporated into the urban-runoff model, SLAMM.

Source-area suspended solids and phosphorus loads from the Monroe and Harper Basins were determined based on measured concentrations that were multiplied by water volume estimated by use of SLAMM. Collected data were used to calibrate and increase confidence in water volumes, suspended solids, and phosphorus source-area loads estimated by SLAMM. The calibrated model calculated water volumes to within 23 and 24 percent of those measured at the outfalls of the Monroe and Harper Basins. These calibrated water volumes were then applied to the calibrated suspended-solids and phosphorus concentrations entered into the SLAMM data bases. Suspended-solids loads were estimated by the calibrated SLAMM to be within 4 and 17 percent, total-phosphorus loads within 24 and 28 percent, and dissolved-phosphorus loads within 9 and 10 percent of those measured at the storm-sewer outfall to the Monroe and Harper Basins, respectively.

Streets and lawns are the largest contributors of suspended-solids, total-phosphorus, and dissolved-phosphorus loads in a residential urban basin. Lawns are the largest contributors of total and dissolved phosphorus; however, streets contributed nearly 40 percent of the basin load, as seen in the Monroe Basin. Streets were found to be the largest source of suspended solids.

There was a large difference between geometric mean concentrations of phosphorus in lawn runoff from 1994 to 1995. Phosphorus data collected from lawns in the Harper and Lakeland Basins during 1995 are remarkably similar, which suggests that the phosphorus concentration in lawn runoff is affected by some variable or variables that are not yet understood.

Street-dirt samples indicate that approximately 75 percent of the sediment mass resides in the >250 μm particle-size fraction. Less than 5 percent of the mass can be found in the particle sizes less than 63 μm. The >250 μm particle-size fraction also contributed nearly 50 percent of the total-phosphorus mass, and the leaf fraction contributed an additional 30 percent. In each particle-size fraction, approximately 25 percent of the total-phosphorus mass is derived from leaves or other vegetation.

A possible limitation of this study may be that in order for the sum of the source-area loads to match the basin-outfall loads, it was assumed that the concentrations of suspended solids in street runoff were about 5 times higher than the concentrations measured. However, the analysis of load distributions based only on unadjusted monitored concentration data shows little change in the distributions. In addition, samples from more rain events were collected in this study than previous source-area studies. Also, improved data-collection equipment were used during this study. Both of these factors lead to greater confidence in the study results.

Most of the measured suspended-solids concentrations were lower than those measured from previous studies. However, when comparing concentration results in this study to results from earlier studies, it is important to note that with the exception of the Marquette study, previous studies used earlier generation source-area sampling equipment. In Marquette, Mich., the soils are considerably more sandy than those in Madison, which may explain why the suspended-solids concentrations determined for the Marquette study are higher than those from Madison even though both studies used the same sample-collection equipment.

The recalibration of the SLAMM model results in an improved model that should more accurately simulate phosphorus and sediment runoff loads in Wisconsin than the earlier version of the model. The newly created lawn-runoff coefficients for Madison represent a compromise between the two previous soil-type options available for model input, which probably represented runoff extremes. The runoff coefficients calculated for Madison should probably be applied to most urban lawns in Wisconsin unless soils are known to be either sandy or clayey. The phosphorus- and sediment-concentration data bases created for this study are the largest to date using the most advanced source-area sample collection technology available.

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APPENDIX A—
Detailed Study Data Tables

Table A1. Rainfall and runoff statistics for the Monroe Basin, Madison, Wis., 1994
[h, hour; min, minute; in/h, inches per hour; ft^3, cubic feet]

Rain start (date & 24-h time)	Rain end (date & 24-h time)	Rain duration (h:min)	Total rain (inches)	Rainfall intensity (in/h)	Total runoff volume (ft^3)
05/23/94 18:03	05/23/94 20:55	02:52	0.27	0.09	41,524
05/25/94 17:09	05/26/94 02:29	09:20	.09	.01	7,059
06/05/94 15:00	06/05/94 16:54	01:54	.11	.06	19,544
06/07/94 11:59	06/07/94 12:13	00:14	.04	.17	2,212
06/11/94 15:14	06/11/94 15:22	00:08	.21	1.62	43,269
06/13/94 01:31	06/13/94 03:43	02:12	.28	.13	38,059
06/18/94 17:33	06/18/94 23:55	06:22	.67	.11	141,091
06/19/94 22:34	06/20/94 04:53	06:19	.24	.04	29,264
06/23/94 07:37	06/24/94 06:06	22:29	1.69	.08	300,067
06/25/94 20:51	06/26/94 02:18	05:27	.65	.12	146,500
06/28/94 02:19	06/28/94 02:26	00:07	.04	.34	5,676
07/14/94 00:37	07/14/94 04:46	04:09	.18	.04	18,948
07/20/94 00:38	07/20/94 07:59	06:21	.46	.07	72,369
07/24/94 19:49	07/24/94 22:16	02:27	.12	.05	7,759
08/03/94 13:38	08/04/94 03:37	13:59	1.73	.12	207,369
08/10/94 05:14	08/10/94 23:52	18:38	1.47	.08	285,708
08/12/94 13:51	08/13/94 02:41	12:50	.12	.01	9,772
08/18/94 04:46	08/18/94 09:51	05:05	.55	.11	112,761
08/30/94 10:33	08/30/94 20:05	09:28	.28	.03	63,884
09/14/94 00:40	09/14/94 10:05	09:25	.45	.05	110,713
09/15/94 20:02	09/16/94 02:07	06:05	.60	.10	134,300
09/22/94 07:40	09/22/94 11:56	04:16	.20	.05	25,514
10/22/94 17:04	10/22/94 17:58	00:54	.04	.04	1,279
11/05/94 11:53	11/06/94 00:44	12:51	.60	.05	107,456
11/13/94 17:17	11/13/94 21:28	04:11	.22	.05	32,633

Table A2. Rainfall and runoff statistics for the Harper Basin, Madison, Wis., 1995

[h, hour; min, minute; in/h, inches per hour; ft^3, cubic feet]

Rain start (date & 24-h time)	Rain end (date & 24-h time)	Rain duration (h:min)	Total rain (inches)	Rainfall intensity (in/h)	Total runoff volume (ft^3)
06/26/95 13:39	06/26/95 15:49	02:10	0.26	0.12	7,111
07/04/95 10:26	07/04/95 17:13	06:47	.17	.03	3,698
07/04/95 23:38	07/05/95 05:10	05:32	.79	.14	30,637
07/05/95 14:26	07/05/95 15:01	00:35	.36	.62	13,945
07/15/95 18:29	07/15/95 22:33	04:04	.50	.12	15,915
07/19/95 13:38	07/19/95 15:15	01:37	.15	.09	3,439
07/19/95 22:02	07/20/95 00:34	02:32	.16	.06	4,847
07/22/95 10:46	07/23/95 02:45	07:45	.79	.10	25,704
07/24/95 09:16	07/24/95 09:54	00:43	.18	.25	4,579
07/25/95 19:04	07/26/95 00:12	05:08	.10	.02	1,331
07/27/95 17:15	07/28/95 00:52	07:37	.24	.03	8,545
07/31/95 13:50	07/31/95 23:09	09:19	.21	.02	7,759
08/16/95 00:35	08/16/95 02:56	02:21	.08	.03	1,020
08/16/95 16:19	08/16/95 17:45	01:26	.61	.43	25,790
08/16/95 23:33	08/17/95 00:51	01:18	.38	.29	17,081
08/19/95 08:59	08/19/95 11:18	02:19	.51	.22	19,336
08/28/95 09:23	08/28/95 13:35	04:12	.80	.19	33,506
08/28/95 20:16	08/29/95 04:17	08:01	.15	.02	4,553
09/07/95 07:34	09/07/95 11:38	04:04	.19	.05	5,867
09/19/95 06:24	09/20/95 01:05	18:41	.74	.04	23,043
09/20/95 18:57	09/21/95 04:11	09:14	.14	.02	2,436
09/30/95 11:05	09/30/95 13:16	02:11	.17	.08	6,402
09/30/95 18:13	10/01/95 04:13	10:00	.22	.02	8,588
10/19/95 14:40	10/19/95 19:27	04:47	.32	.07	12,372
10/31/95 15:51	11/01/95 19:55	24:04	1.28	.05	61,992

Table A3. Concentrations of total phosphorus at monitored source areas in the Monroe Basin, Madison, Wis., 1994

[All concentrations are in milligrams per liter; n.d., no data]

Date	Driveways	Lawns	Pitched roofs	Flat roofs	Parking lot	Low-traffic streets	Medium-traffic streets	High-traffic streets	Storm-sewer outfall
05/23/94	1.330	n.d.	0.270	0.330	0.720	2.230	2.040	1.470	1.36
05/25/94	.370	n.d.	.040	.180	.080	.730	.930	.180	.67
06/05/94	3.100	n.d.	.110	.700	.180	2.100	.750	.350	2.79
06/07/94	.570	n.d.	.180	n.d.	.230	1.870	.770	.470	1.1
06/11/94	.420	.850	.130	.150	.150	.420	.310	.090	2.39
06/13/94	.230	n.d.	.030	.040	.030	.220	.180	.090	.24
06/18/94	2.207	1.425	.112	.170	.243	1.121	.326	.296	.576
06/19/94	.669	n.d.	.069	.078	.044	.286	.137	.099	.277
06/23/94	.180	.265	.011	.018	.007	.007	.040	.076	n.d.
06/25/94	.439	.524	.045	.041	.041	.226	.112	.137	n.d.
06/28/94	.416	.079	.109	.491	.116	.313	.141	.160	1.709
07/14/94	.264	n.d.	.193	n.d.	.080	.473	.107	.113	.424
07/20/94	.203	.949	.060	n.d.	.048	.271	.093	.093	.336
07/24/94	.315	n.d.	n.d.	n.d.	.180	.428	.249	.181	.655
08/03/94	.572	2.215	.070	.175	.126	.305	.137	.171	.569
08/10/94	.201	.416	.020	.066	.043	.266	.100	.153	.181
08/12/94	.191	n.d.	.053	n.d.	.092	.251	.072	.178	.19
08/18/94	.190	1.072	.050	.093	.135	.222	.125	.169	.536
08/30/94	.967	2.168	.049	.098	.072	.387	.108	.159	.596
09/14/94	.227	1.109	.041	.121	.088	.204	n.d.	.161	.465
09/15/94	.262	1.031	.031	.046	.152	.211	.096	.108	.40
09/22/94	.348	n.d.	.040	.445	.071	.213	.288	.247	.798
10/22/94	1.526	n.d.	.240	.475	n.d.	1.763	.407	.440	n.d.
11/05/94	.575	1.482	.168	.116	.255	3.901	.843	.229	1.622
11/13/94	.604	.793	.132	.096	.097	.225	.298	.166	.826

Table A4. Concentrations of dissolved phosphorus at monitored source areas in the Monroe Basin, Madison, Wis., 1994

[All concentrations are in milligrams per liter; n.d., no data]

Date	Driveways	Lawns	Pitched roofs	Flat roofs	Parking lot	Low-traffic streets	Medium-traffic streets	High-traffic streets	Storm-sewer outfall
05/23/94	0.248	n.d.	n.d.	0.126	0.177	0.710	0.794	0.263	0.682
05/25/94	.083	n.d.	0.010	.021	.039	.233	.383	.070	.333
06/05/94	1.650	n.d.	.008	.175	.020	.905	.246	.146	1.2
06/07/94	.189	n.d.	.002	n.d.	.003	1.050	.149	.027	.033
06/11/94	.181	.664	.004	.020	n.d.	n.d.	n.d.	n.d.	.119
06/13/94	.116	n.d.	.012	.002	.010	.192	.150	.087	.12
06/18/94	.670	.631	.016	.026	.005	.377	.073	.031	.073
06/19/94	.398	n.d.	.022	.080	.049	.147	.080	.033	.09
06/23/94	.021	.115	.006	.005	.007	.021	.023	.024	n.d.
06/25/94	.067	.226	.012	.013	.005	.039	.029	.017	n.d.
06/28/94	.096	.028	.028	n.d.	.030	.041	.007	.024	.109
07/14/94	.112	n.d.	.103	n.d.	.024	.022	.038	.012	.193
07/20/94	.055	.590	.023	n.d.	.003	.075	.002	.007	.101
07/24/94	.067	n.d.	n.d.	n.d.	.080	.173	.006	.007	.33
08/03/94	.073	.968	.039	.022	.008	n.d.	.004	.020	.175
08/10/94	.048	.229	.015	.015	.008	.161	.021	.029	.079
08/12/94	.066	n.d.	.018	n.d.	.006	.074	.008	.009	.045
08/18/94	.054	.467	.011	.019	.070	.130	.023	.061	.139
08/30/94	.482	.159	.064	.046	.030	.114	.034	.017	.207
09/14/94	.127	.746	.014	.046	.020	.100	.030	.035	.178
09/15/94	.089	.679	.013	.009	.131	.108	.022	.007	.013
09/22/94	.167	n.d.	n.d.	n.d.	.012	.046	.051	.007	.31
10/22/94	1.362	n.d.	.171	n.d.	n.d.	1.256	.449	.136	n.d.
11/05/94	.220	1.057	.087	.013	.161	3.147	.568	.076	1.197
11/13/94	.457	.671	.064	.010	.044	.143	.196	.043	.547

Table A5. Concentrations of total-suspended solids at monitored source areas in the Monroe Basin, Madison, Wis., 1994
[All concentrations are in milligrams per liter; n.d., no data]

Date	Driveways	Lawns	Pitched roofs	Flat roofs	Parking lot	Low-traffic streets	Medium-traffic streets	High-traffic streets	Storm-sewer outfall
05/23/94	437	n.d.	54	36	251	231	315	412	305
05/25/94	72	n.d.	22	17	94	99	138	65	100
06/05/94	403	n.d.	23	67	109	231	91	76	390
06/07/94	65	n.d.	n.d.	n.d.	34	59	111	55	101
06/11/94	239	109	90	45	449	568	151	85	1083
06/13/94	209	n.d.	31	27	57	57	n.d.	41	44
06/18/94	807	137	31	30	262	239	115	106	305
06/19/94	177	n.d.	14	15	36	53	25	51	65
06/23/94	187	59	n.d.	n.d.	14	31	52	101	270
06/25/94	411	152	7	n.d.	74	83	45	64	n.d.
06/28/94	125	1	2	n.d.	n.d.	58	20	15	166
07/14/94	69	n.d.	25	n.d.	29	72	37	36	68
07/20/94	70	61	17	n.d.	34	60	34	31	129
07/24/94	63	n.d.	n.d.	n.d.	15	36	29	46	32
08/03/94	542	79	4	20	112	106	36	121	285
08/10/94	87	70	18	17	24	30	42	80	60
08/12/94	32	n.d.	7	n.d.	53	50	34	98	56
08/18/94	20	149	6	2	31	49	64	52	372
08/30/94	137	70	4	5	21	94	17	54	254
09/14/94	9	108	n.d.	n.d.	44	22	26	54	184
09/15/94	122	125	9	n.d.	54	12	47	47	233
09/22/94	26	n.d.	n.d.	167	15	32	55	131	109
10/22/94	67	n.d.	25	67	n.d.	81	75	132	n.d.
11/05/94	155	52	29	2	44	74	99	58	118
11/13/94	82	17	13	5	32	67	39	18	113

Table A6. Concentrations of total phosphorus at monitored source areas in the Harper Basin, Madison, Wis., 1995

[All concentrations are in milligrams per liter; n.d., no data]

Date	Driveways	Lawns	Roofs	Low-tree-canopy streets	Medium-tree-canopy streets	High-tree-canopy streets	Storm-sewer outfall
06/26/95	0.33	10.72	0.54	0.22	0.93	3.30	0.85
07/04/95	.15	n.d.	.24	.17	.36	2.37	.4
07/04/95	.14	2.40	.24	.10	.22	.66	.39
07/05/95	.26	1.32	.14	.08	.26	.57	.23
07/15/95	.21	3.61	.39	.20	.42	1.75	.38
07/19/95	.39	n.d.	.36	.11	.22	1.15	.3
07/19/95	.12	n.d.	.14	.08	.15	.80	.23
07/22/95	.08	1.08	.10	.06	.30	.24	.24
07/24/95	.12	n.d.	.21	.09	.14	.57	n.d.
07/25/95	.12	n.d.	.11	.12	.22	.52	.16
07/27/95	.16	n.d.	.15	.10	.29	.71	.26
07/31/95	.20	n.d.	.19	.14	.36	.85	.34
08/16/95	.21	3.81	.26	.30	.66	2.25	.28
08/16/95	.14	1.82	.08	.08	.18	1.70	.325
08/16/95	.05	.60	.04	.03	.07	.46	.18
08/19/95	.37	.50	.09	.02	.11	.36	.27
08/28/95	.58	1.39	.11	.06	.18	.55	1.05
08/28/95	.05	n.d.	.10	.04	.07	.74	n.d.
09/07/95	.76	n.d.	.11	.10	.37	1.37	.67
09/19/95	.05	.48	.17	.04	.18	.36	.16
09/20/95	.04	n.d.	.02	.03	.04	.42	.14
09/30/95	.40	1.69	.32	.15	.36	2.48	.64
09/30/95	.26	n.d.	.40	.07	.20	1.28	.3
10/19/95	.69	2.24	.22	.26	.87	1.22	.97
10/31/95	.22	1.13	.05	.05	.63	.25	.22

Table A7. Concentrations of dissolved phosphorus at monitored source areas in the Harper Basin, Madison, Wis., 1995

[All concentrations are in milligrams per liter; <, less than; n.d., no data]

Date	Driveways	Lawns	Roofs	Low-tree-canopy streets	Medium-tree-canopy streets	High-tree-canopy streets	Storm-sewer outfall
06/26/95	0.14	8.77	0.36	0.06	0.45	1.78	0.44
07/04/95	.05	n.d.	.12	.04	.13	1.14	.22
07/04/95	.01	1.51	.05	.03	.07	.35	.09
07/05/95	.08	.81	.05	.04	.07	.27	.08
07/15/95	.10	3.12	.22	.09	.13	1.06	.23
07/19/95	.19	n.d.	.22	.05	.10	.44	.14
07/19/95	.03	n.d.	.04	.02	.04	.16	.08
07/22/95	.07	.62	.05	.01	.05	.13	.09
07/24/95	.03	n.d.	.11	.02	.04	.13	n.d.
07/25/95	<.01	n.d.	.04	.01	.03	.09	.13
07/27/95	.02	n.d.	.07	.02	.14	.28	.12
07/31/95	.06	n.d.	.09	.02	.06	.04	.13
08/16/95	.18	1.34	.12	.08	.26	1.02	.19
08/16/95	.04	.40	.03	.02	.06	.34	.115
08/16/95	.02	.17	.04	.01	.04	.08	.09
08/19/95	.19	.29	.04	<.01	.06	.19	.07
08/28/95	.39	1.32	.14	.02	.08	.29	.18
08/28/95	.04	n.d.	.06	.02	.03	.44	n.d.
09/07/95	.36	n.d.	.05	.05	.14	.68	.24
09/19/95	.02	.19	.13	.02	.10	.18	.08
09/20/95	.02	n.d.	.01	.02	.02	.24	.06
09/30/95	.17	1.27	.15	.02	.08	1.44	.26
09/30/95	.03	n.d.	.29	.02	.08	.93	.14
10/19/95	.33	n.d.	.13	.19	.42	.83	.72
10/31/95	.14	.18	.03	.02	.32	.05	.15

Table A8. Concentrations of total-suspended solids at monitored source areas in the Harper Basin, Madison, Wis., 1995

[All concentrations are in milligrams per liter; n.d., no data; <, less than]

Date	Driveways	Lawns	Roofs	Low-tree-canopy streets	Medium-tree-canopy streets	High-tree-canopy streets	Storm-sewer outfall
06/26/95	163	120	49	116	200	510	160
07/04/95	17	n.d.	14	42	61	132	64
07/04/95	65	172	46	132	139	646	206
07/05/95	93	154	17	60	111	352	170
07/15/95	78	78	34	101	192	182	93
07/19/95	25	n.d.	10	28	39	118	39
07/19/95	19	n.d.	34	59	60	253	81
07/22/95	176	166	16	101	211	40	115
07/24/95	9	n.d.	22	33	35	97	n.d.
07/25/95	15	n.d.	13	70	39	123	20
07/27/95	31	n.d.	21	55	122	101	75
07/31/95	31	n.d.	17	69	149	135	85
08/16/95	32	n.d.	15	114	210	n.d.	11
08/16/95	63	164	18	89	150	786	307
08/16/95	6	50	4	13	18	111	41
08/19/95	29	193	7	23	40	122	641
08/28/95	149	164	10	28	61	123	493
08/28/95	6	n.d.	<2	6	8	63	n.d.
09/07/95	52	n.d.	114	62	141	124	152
09/19/95	5	135	4	10	26	50	30
09/20/95	4	n.d.	<2	5	6	39	10
09/30/95	92	69	56	85	151	242	271
09/30/95	118	n.d.	26	39	58	217	106
10/19/95	132	178	34	40	132	34	125
10/31/95	26	76	2	11	88	69	36

Table A9. Concentrations of total and dissolved phosphorus and suspended solids from lawn runoff and at the storm-sewer outfall in the Lakeland Basin, Madison, Wis., 1995

[All concentrations are in milligrams per liter; n.d., no data]

Sample date	Dissolved phosphorus		Total phosphorus		Suspended solids	
	Lawns	Storm-sewer outfall	Lawns	Storm-sewer outfall	Lawns	Storm-sewer outfall
6/26/95	5.46	0.83	9.05	1.74	242	409
7/5/95	1.05	.08	2.06	.40	129	176
7/6/95	n.d.	.17	1.51	.47	n.d.	296
7/15/95	2.15	.08	2.99	.46	80	159
7/22/95	.74	.06	1.35	.40	75	132
8/16/95	1.32	.22	2.48	.56	n.d.	67
8/16/95	.30	.10	.58	.33	72	114
8/17/95	.18	.09	.75	.24	35	76
8/20/95	n.d.	.12	.72	.26	n.d.	67
8/28/95	1.31	.21	1.58	.37	29	75
9/7/95	3.37	.29	4.68	.55	99	126
9/20/95	.37	.23	1.04	.42	150	30
10/19/95	n.d.	1.12	2.59	1.52	184	64
11/2/95	.18	.29	1.36	.42	108	29

Table A10. Comparison of water volumes measured at the Monroe Basin storm-sewer outfall to those simulated by the model after calibration, Madison, Wis., 1994

[ft^3, cubic feet]

Date	Rain depth (inches)	Measured storm-sewer outfall volumes (ft^3)	Modeled storm-sewer outfall volumes (ft^3)	Percent difference
05/23/94	0.27	41,524	40,009	-4
05/25/94	.09	7,059	9,525	35
06/05/94	.11	19,544	12,251	-37
06/07/94	.04	2,212	2,672	21
06/11/94	.21	43,269	27,415	-37
06/13/94	.28	38,059	42,313	11
06/18/94	.67	141,091	142,974	1
06/19/94	.24	29,264	33,448	14
06/23/94	1.69	300,067	447,706	49
06/25/94	.65	146,500	137,125	-6
06/28/94	.04	5,676	2,672	-53
07/14/94	.18	18,948	22,300	18
07/20/94	.46	72,369	87,858	21
07/24/94	.12	7,759	13,673	76
08/03/94	1.73	207,369	459,257	122
08/10/94	1.47	285,708	381,356	34
08/12/94	.12	9,772	13,673	40
08/18/94	.55	112,761	109,877	-3
08/30/94	.28	63,884	42,313	-34
09/14/94	.45	110,713	85,509	-23
09/15/94	.60	134,300	122,929	-9
09/22/94	.20	25,514	25,522	0
10/22/94	.04	1,279	2,672	109
11/05/94	.60	107,456	122,929	14
11/13/94	.22	32,633	29,367	-10
Totals		1,964,730	2,417,345	23

Table A11. Comparison of water volumes measured at the Harper Basin storm-sewer outfall to those simulated by the model after calibration, Madison, Wis., 1995

[ft^3, cubic feet]

Date	Rain depth (inches)	Measured storm-sewer outfall volumes (ft^3)	Modeled storm-sewer outfall volumes (ft^3)	Percent difference
6/26/95	0.26	7,111	5,373	-24
7/4/95	.17	3,698	2,925	-21
7/4/95	.79	30,637	26,217	-14
7/5/95	.36	13,945	9,044	-35
7/15/95	.50	15,915	14,091	-12
7/19/95	.15	3,439	2,509	-27
7/19/95	.16	4,847	2,715	-44
7/22/95	.79	25,704	26,217	2
7/24/95	.18	4,579	3,140	-31
7/25/95	.10	1,331	1,520	14
7/27/95	.24	8,545	4,746	-45
7/31/95	.21	7,759	3,872	-50
8/16/95	.08	1,020	1,149	13
8/16/95	.61	25,790	18,220	-29
8/16/95	.38	17,081	9,885	-42
8/19/95	.51	19,336	14,447	-25
8/28/95	.80	33,506	26,652	-21
8/28/95	.15	4,553	2,509	-45
9/7/95	.19	5,867	3,360	-43
9/19/95	.74	23,043	23,884	4
9/20/95	.14	2,436	2,308	-5
9/30/95	.17	6,402	2,925	-54
9/30/95	.22	8,588	4,154	-52
10/19/95	.32	12,372	7,468	-40
10/31/95	1.28	61,992	47,150	-24
Totals		349,496	266,480	-24

Table A12. Comparison of measured and modeled suspended-solids loads at the storm-sewer outfall, Monroe Basin, Madison, Wis., 1994

[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
05/23/94	0.27	791	602	-24
05/25/94	.09	44	416	844
06/05/94	.11	476	601	26
06/07/94	.04	14	315	2,160
06/11/94	.21	2,930	505	-83
06/13/94	.28	105	803	668
06/18/94	.67	2,690	1,097	-59
06/19/94	.24	119	777	554
06/23/94	1.69	5,060	1,768	-65
06/25/94	.65	n.d.	n.d.	n.d.
06/28/94	.04	59	237	303
07/14/94	.18	80	1,005	1,150
07/20/94	.46	583	1,241	113
07/24/94	.12	16	913	5,790
08/03/94	1.73	3,690	2,207	-40
08/10/94	1.47	1,070	2,058	92
08/12/94	.12	34	974	2,750
08/18/94	.55	2,620	1,398	-47
08/30/94	.28	1,010	1,219	20
09/14/94	.45	1,270	1,422	12
09/15/94	.60	1,950	1,417	-27
09/22/94	.20	174	1,178	578
10/22/94	.04	n.d.	n.d.	n.d.
11/05/94	.60	792	1,508	90
11/13/94	.22	230	1,254	445
Total (lbs)		25,800	24,915	-4

Table A13. Comparison of measured and modeled suspended-solids loads at the storm-sewer outfall, Harper Basin, Madison, Wis., 1995
[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
6/26/95	0.26	71	84	18
7/4/95	.17	15	90	509
7/4/95	.79	394	145	-63
7/5/95	.36	148	88	-41
7/15/95	.50	92	135	46
7/19/95	.15	8	101	1,110
7/19/95	.16	25	95	288
7/22/95	.79	185	157	-15
7/24/95	.18	n.d.	n.d.	n.d.
7/25/95	.10	2	77	4,530
7/27/95	.24	40	98	145
7/31/95	.21	41	98	138
8/16/95	.08	1	97	13,750
8/16/95	.61	494	192	-61
8/16/95	.38	44	146	234
8/19/95	.51	774	150	-81
8/28/95	.80	1,030	195	-81
8/28/95	.15	n.d.	n.d.	n.d.
9/7/95	.19	56	136	144
9/19/95	.74	43	213	393
9/20/95	.14	2	137	8,910
9/30/95	.17	108	158	46
9/30/95	.22	57	155	173
10/19/95	.32	97	192	99
10/31/95	1.28	139	285	105
Total (lbs)		3,870	3,224	-17

Table A14. Comparison of measured and modeled total-phosphorus loads at the storm-sewer outfall, Monroe Basin, Madison, Wis., 1994

[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
05/23/94	0.27	3.53	0.82	-77
05/25/94	.09	.30	.31	4
06/05/94	.11	3.40	.43	-87
06/07/94	.04	.15	.20	30
06/11/94	.21	6.46	.52	-92
06/13/94	.28	.57	.98	72
06/18/94	.67	5.07	3.00	-41
06/19/94	.24	.51	.78	55
06/23/94	1.69	n.d.	n.d.	n.d.
06/25/94	.65	n.d.	n.d.	n.d.
06/28/94	.04	.61	.15	-75
07/14/94	.18	.50	.74	47
07/20/94	.46	1.52	2.00	32
07/24/94	.12	.32	.62	95
08/03/94	1.73	7.37	11.00	49
08/10/94	1.47	3.23	10.00	210
08/12/94	.12	.12	.65	464
08/18/94	.55	3.77	3.00	-21
08/30/94	.28	2.38	1.00	-58
09/14/94	.45	3.21	2.00	-38
09/15/94	.60	3.35	3.00	-11
09/22/94	.20	1.27	.86	-32
10/22/94	.04	n.d.	n.d.	n.d.
11/05/94	.60	10.88	3.00	-72
11/13/94	.22	1.68	.98	-42
Total (lbs)		60.19	46.00	-24

Table A15. Comparison of measured and modeled total-phosphorus loads at the storm-sewer outfall, Harper Basin, Madison, Wis., 1995
[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
6/26/95	0.26	0.38	0.11	-71
7/4/95	.17	.09	.07	-25
7/4/95	.79	.75	.62	-17
7/5/95	.36	.20	.19	-5
7/15/95	.5	.38	.32	-16
7/19/95	.15	.06	.07	4
7/19/95	.16	.07	.07	-6
7/22/95	.79	.39	.62	61
7/24/95	.18	n.d.	n.d.	n.d.
7/25/95	.1	.01	.05	253
7/27/95	.24	.14	.09	-32
7/31/95	.21	.16	.08	-53
8/16/95	.08	.02	.05	180
8/16/95	.61	.52	.43	-18
8/16/95	.38	.19	.23	19
8/19/95	.51	.33	.33	0
8/28/95	.8	2.20	.64	-71
8/28/95	.15	n.d.	n.d.	n.d.
9/7/95	.19	.25	.08	-67
9/19/95	.74	.23	.58	150
9/20/95	.14	.02	.07	241
9/30/95	.17	.26	.09	-67
9/30/95	.22	.16	.10	-38
10/19/95	.32	.75	.18	-76
10/31/95	1.28	.85	1.00	17
Total (lbs)		8.40	6.05	-28

Table A16. Comparison of measured and modeled dissolved-phosphorus loads at the storm-sewer outfall, Monroe Basin, Madison, Wis., 1994

[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
05/23/94	0.27	1.77	0.32	-82
05/25/94	.09	.15	.05	-65
06/05/94	.11	1.46	.07	-95
06/07/94	.04	.00	.01	212
06/11/94	.21	.32	.16	-49
06/13/94	.28	.29	.35	22
06/18/94	.67	.64	2.00	211
06/19/94	.24	.16	.23	42
06/23/94	1.69	n.d.	n.d.	n.d.
06/25/94	.65	n.d.	n.d.	n.d.
06/28/94	.04	.04	.01	-63
07/14/94	.18	.23	.12	-47
07/20/94	.46	.46	.98	114
07/24/94	.12	.16	.07	-54
08/03/94	1.73	2.27	6.00	165
08/10/94	1.47	1.41	5.00	255
08/12/94	.12	.03	.07	170
08/18/94	.55	.98	1.00	2
08/30/94	.28	.83	.35	-58
09/14/94	.45	1.23	.95	-23
09/15/94	.60	.11	1.00	817
09/22/94	.20	.49	.14	-71
10/22/94	.04	n.d.	n.d.	n.d.
11/05/94	.60	8.03	1.00	-88
11/13/94	.22	1.11	.19	-83
Total (lbs)		22.17	20.07	-9

Table A17. Comparison of measured and modeled dissolved-phosphorus loads at the storm-sewer outfall, Harper Basin, Madison, Wis., 1995
[lbs, pounds; n.d., no data]

Date	Rain depth (inches)	Measured storm-sewer outfall loads (lbs)	Modeled storm-sewer outfall loads (lbs)	Percent difference
6/26/95	0.26	0.20	0.04	-79
7/4/95	.17	.05	.02	-68
7/4/95	.79	.17	.34	95
7/5/95	.36	.07	.09	32
7/15/95	.50	.23	.16	-30
7/19/95	.15	.03	.01	-53
7/19/95	.16	.02	.02	-37
7/22/95	.79	.14	.34	133
7/24/95	.18	n.d.	n.d.	n.d.
7/25/95	.10	.01	.01	-21
7/27/95	.24	.06	.03	-47
7/31/95	.21	.06	.02	-62
8/16/95	.08	.01	.01	-47
8/16/95	.61	.19	.22	16
8/16/95	.38	.10	.11	9
8/19/95	.51	.08	.16	94
8/28/95	.80	.38	.34	-9
8/28/95	.15	n.d.	n.d.	n.d.
9/7/95	.19	.09	.02	-79
9/19/95	.74	.12	.30	161
9/20/95	.14	.01	.01	42
9/30/95	.17	.10	.02	-84
9/30/95	.22	.08	.03	-64
10/19/95	.32	.56	.07	-87
10/31/95	1.28	.58	.63	9
Total (lbs)		3.34	2.99	-10

Table A18. Percentage of overhead tree canopy for monitored streets in selected basins, Madison, Wis.
[%, percent]

Monroe Basin			Harper Basin		
Residential streets (%)	Glenway (%)	Monroe (%)	Nova (%)	Luster (%)	Woodward (%)
33	15	13	5	34	78

Table A19. Total sediment mass and percentage by size fraction in street-dirt samples in the Monroe Basin, Madison, Wis., 1994

[µm, micrometer; >, greater than; %, percent]

Total sediment mass (grams) and percentage of total by size fraction						
Date	25 µm	25–63 µm	63–250 µm	>250 µm	Leaves	Total mass
Monroe Street						
4/10/94	4.7	25.6	226.8	1,543.2	0.0	1,800.4
	.3%	1.4%	12.6%	85.7%	.0%	
6/3/94	1.4	10.2	45.1	171.4	.2	228.3
	.6%	4.5%	19.7%	75.1%	.0%	
7/15/94	.1	3.6	25.7	98.5	.0	127.9
	.0%	2.8%	20.1%	77.0%	.0%	
8/30/94	.9	4.7	24.3	76.5	.1	106.4
	.8%	4.4%	22.8%	71.9%	.0%	
9/30/94	1.5	11.0	29.2	51.5	.8	94.0
	1.5%	11.7%	31.1%	54.8%	.9%	
10/28/94	.6	4.3	16.6	91.6	1.8	114.8
	.5%	3.7%	14.4%	79.8%	1.6%	
Sum	9.2	59.7	368.6	2,036.3	2.9	2,476.8
	.4%	2.4%	14.9%	82.2%	.1%	
Glenway						
4/10/94	4.2	27.4	239.9	1,152.9	0.7	1,425.1
	.3%	1.9%	16.8%	80.9%	.0%	
6/3/94	2.1	11.9	68.2	246.9	71.9	401.0
	.5%	3.0%	17.0%	61.6%	17.9%	
7/15/94	.3	3.0	26.0	116.0	2.2	147.4
	.2%	2.0%	17.7%	78.7%	1.5%	
8/30/94	.7	3.6	30.8	127.5	7.5	170.0
	.4%	2.1%	18.1%	75.0%	4.4%	
9/30/94	.4	3.7	36.0	137.2	20.5	197.8
	.2%	1.9%	18.2%	69.3%	10.4%	
10/28/94	.6	3.8	30.2	128.5	353.1	516.3
	.1%	.7%	5.9%	24.9%	68.4%	
Sum	8.3	53.5	432.1	1,912.5	456.2	2,862.6
	.3%	1.9%	15.1%	66.8%	15.9%	
Residential streets						
4/10/94	13.5	113.2	583.5	2,793.0	14.4	3,517.6
	.4%	3.2%	16.6%	79.4%	.4%	
6/3/94	15.7	98.5	491.8	1,777.5	99.7	2,483.2
	.6%	4.0%	19.8%	71.6%	4.0%	
7/15/94	2.8	17.1	126.1	476.0	6.9	628.9
	.4%	2.7%	20.0%	75.7%	1.1%	
8/30/94	1.4	7.8	88.5	305.0	57.8	460.5
	.3%	1.7%	19.2%	66.2%	12.6%	
9/30/94	.5	3.6	27.1	125.0	37.1	193.3
	.3%	1.8%	14.0%	64.7%	19.2%	
10/28/94	.5	3.3	29.1	174.7	310.2	517.7
	.1%	.6%	5.6%	33.7%	59.9%	
Sum	34.5	243.6	1,346.9	5,654.8	526.5	7,806.2
	.4%	3.1%	17.3%	72.4%	6.7%	

Table A20. Total sediment mass and percentage by size fraction in street-dirt samples in the Harper Basin, Madison, Wis., 1995

[µm, micrometer; %, percent]

Total sediment mass (grams) and percentage of total by size fraction						
Date	25 µm	25–63 µm	63–250 µm	>250 µm	Leaves	Total mass
			Nova			
6/15/95	10.0	36.6	200.8	276.3	6.4	530.1
	1.9%	6.9%	37.9%	52.1%	1.2%	
7/13/95	1.7	16.1	106.3	186.9	2.3	313.2
	.5%	5.1%	33.9%	59.7%	.7%	
8/23/95	2.6	16.7	110.3	219.4	6.8	355.9
	.7%	4.7%	31.0%	61.6%	1.9%	
9/28/95	5.1	8.5	88.0	176.6	4.2	282.4
	1.8%	3.0%	31.2%	62.5%	1.5%	
10/26/95	.6	8.1	74.6	179.2	24.8	287.4
	.2%	2.8%	26.0%	62.4%	8.6%	
Sum	20.0	86.1	580.0	1,038.4	44.5	1,769.0
	1.1%	4.9%	32.8%	58.7%	2.5%	
			Luster			
6/15/95	16.6	145.9	405.4	557.4	48.9	1,174.2
	1.4%	12.4%	34.5%	47.5%	4.2%	
7/13/95	3.6	64.7	276.9	373.9	61.6	780.7
	.5%	8.3%	35.5%	47.9%	7.9%	
8/23/95	7.3	62.3	279.3	465.1	28.7	842.6
	.9%	7.4%	33.1%	55.2%	3.4%	
9/28/95	4.5	29.7	147.5	222.8	66.3	470.7
	.9%	6.3%	31.3%	47.3%	14.1%	
10/26/95	2.2	18.2	142.0	222.4	296.2	680.9
	.3%	2.7%	20.8%	32.7%	43.5%	
Sum	34.1	320.8	1,250.9	1,841.6	501.7	3,949.1
	.9%	8.1%	31.7%	46.6%	12.7%	
			Woodward			
6/15/95	7.1	55.1	345.5	999.0	32.9	1,439.6
	.5%	3.8%	24.0%	69.4%	2.3%	
7/13/95	1.6	13.4	145.3	491.2	14.1	665.5
	.2%	2.0%	21.8%	73.8%	2.1%	
8/23/95	3.9	18.5	157.6	410.3	5.3	595.5
	.7%	3.1%	26.5%	68.9%	.9%	
9/28/95	2.8	23.0	200.3	469.3	29.7	725.1
	.4%	3.2%	27.6%	64.7%	4.1%	
10/26/95	1.4	2.3	79.9	514.0	1,144.0	1,741.7
	.0%	.1%	4.6%	29.5%	65.7%	
Sum	16.8	112.3	928.6	2,883.8	1,226.0	5,167.4
	.3%	2.2%	18.0%	55.8%	23.7%	

Table A21. Total phosphorus mass by size fraction and percentage of mass by street in street-dirt samples in the Monroe Basin, Madison, Wis., 1994

[mg, milligrams; µm, micrometers; <, less than]

Collection date	Street	Total phosphorus mass (mg) in dirt samples by size fraction						Percent by street
		<25 µm	25–63 µm	63–250 µm	>250 µm	Leaves	Total	
4/10/94	Monroe Street	1.41	7.30	28.35	263.90	0.00	300.96	31
	Glenway	1.20	8.16	47.98	157.95	1.11	216.41	2
	Residential streets	6.85	46.62	196.64	195.51	5.49	451.10	47
	Total	9.46	62.08	272.98	617.36	6.60	968.47	100
6/3/94	Monroe Street	.45	3.76	8.87	35.98	.46	49.53	4
	Glenway	1.11	7.91	33.02	164.67	125.97	332.68	29
	Residential streets	3.92	42.76	166.71	419.50	149.15	782.04	67
	Total	5.48	54.43	208.60	620.15	275.58	1,164.25	100
7/15/94	Monroe Street	.04	1.18	4.21	15.76	.00	21.19	12
	Glenway	.04	.70	5.05	23.43	2.24	31.45	18
	Residential streets	1.26	7.34	28.24	79.96	5.38	122.19	70
	Total	1.34	9.22	37.50	119.15	7.61	174.82	100
8/30/94	Monroe Street	.28	1.60	4.03	10.25	.07	16.22	6
	Glenway	.16	1.33	7.35	31.48	12.00	52.32	21
	Residential streets	.39	2.83	18.05	62.23	98.26	181.75	73
	Total	.83	5.76	29.42	103.96	110.33	250.30	100
9/30/94	Monroe Street	.34	2.09	5.58	21.06	.73	29.79	11
	Glenway	.08	1.09	11.17	59.25	36.78	108.37	40
	Residential streets	.16	1.34	7.19	30.00	95.12	133.81	49
	Total	.58	4.52	23.94	110.31	132.63	271.98	100
10/28/94	Monroe Street	.18	1.39	5.71	16.95	3.56	27.80	3
	Glenway	.25	1.88	13.09	112.28	125.00	252.50	28
	Residential streets	.25	1.67	11.71	126.10	475.23	614.96	69
	Total	.67	4.94	30.51	255.33	603.79	895.25	100
All event totals								
	Monroe Street	445.5	12.0%					
	Glenway	993.7	26.7%					
	Residential streets	2,285.8	61.4%					
	Total	3,725.1	100.0%					

Table A22. Total phosphorus mass and percentage per square foot of pavement, by size fraction, in street-dirt samples in the Monroe Basin, Madison, Wis., 1994

[µm, micrometer; <, less than; >, greater than; %, percent; --, no data]

Collection date	Total phosphorus mass (grams) per square foot of pavement and percentage by size fraction					
	<25 µm	25–63 µm	63–250 µm	>250 µm	Leaves	Total
Monroe Street						
4/10/94	0.00	0.03	0.10	0.94	--	1.07
	.5%	2.4%	9.4%	87.7%	--	
6/3/94	.00	.01	.03	.13	0.00	.18
	.9%	7.6%	17.9%	72.7%	.9%	
7/15/94	.00	.00	.02	.06	--	.08
	.2%	5.6%	19.9%	74.4%	--	
8/30/94	.00	.00	.01	.04	.00	.06
	1.7%	9.9%	24.8%	63.2%	.4%	
9/30/94	.00	.00	.02	.08	.00	.11
	1.1%	7.0%	18.7%	70.7%	2.4%	
10/28/94	.00	.00	.02	.06	.01	.10
	.7%	5.0%	20.6%	61.0%	12.8%	
Total	.00	.06	.20	1.30	.02	1.59
	.6%	3.9%	12.7%	81.7%	1.1%	
Glenway						
4/10/94	0.00	0.04	0.23	0.76	0.00	1.05
	.6%	3.8%	22.2%	73.0%	.5%	
6/3/94	.00	.038	.16	.80	.61	1.61
	.3%	2.4%	9.9%	49.5%	37.9%	
7/15/94	.00	.00	.02	.11	.01	.15
	.1%	2.2%	16.1%	74.5%	7.1%	
8/30/94	.00	.00	.04	.15	.06	.25
	.3%	2.5%	14.0%	60.2%	22.9%	
9/30/94	.00	.00	.05	.29	.18	.52
	.0%	1.0%	10.3%	54.7%	33.9%	
10/28/94	.00	.00	.06	.54	.60	1.22
	.0%	.7%	5.2%	44.5%	49.5%	
Total	.01	.06	.57	2.66	1.47	4.77
	.2%	1.3%	11.9%	55.7%	30.8%	
Residential streets						
4/10/94	0.04	0.29	1.23	1.22	0.03	2.82
	1.5%	10.3%	43.6%	43.3%	1.2%	
6/3/94	.02	.27	1.04	2.62	.93	4.89
	.5%	5.5%	21.3%	53.6%	19.1%	
7/15/94	.00	.05	.18	.50	.03	.76
	1.0%	6.0%	23.1%	65.4%	4.4%	
8/30/94	.00	.02	.11	.39	.61	1.14
	.2%	1.6%	9.9%	34.2%	54.1%	
9/30/94	.00	.00	.04	.19	.59	.84
	.1%	1.0%	5.4%	22.4%	71.1%	
10/28/94	.00	.01	.07	.79	2.97	3.84
	.0%	.3%	1.9%	20.5%	77.3%	
Total	.08	.64	2.68	5.71	5.18	14.29
	.6%	4.5%	18.7%	40.0%	36.3%	

APPENDIX B—
SLAMM Data File Descriptions

APPENDIX B.

Source Loading and Management Model (SLAMM) Data File Description

The Monroe and Harper Basins are composed of 232.2 and 41.1 acres of residential and commercial land uses (see table 1). Each basin has varying degrees of connectedness within each source area. The more connected a source area, the greater the efficiency in transport of water, sediment, and pollutants. In the Harper Basin, 100 percent of parking lots and sidewalks are directly connected, whereas 87 percent of driveways and only 13 percent of residential roofs are directly connected, the remainder being partially connected. In the Monroe Basin, 2 percent of residential roofs, 69 percent of driveways, 65 percent of sidewalks, and 100 percent of parking lots and commercial roofs are directly connected. Streets are a major influence for water, sediment, and phosphorus in both the Harper and Monroe Basins. The physical nature of the streets, as well as the control practices implemented for them, help determine the contribution of each element listed above. The streets of varying traffic density and overhead canopy for Monroe and Harper study areas as well as their control practices are described in table B1.

Table B1. Street descriptions and control practices used for Monroe and Harper Source Loading and Management Model data files

[--, no control practice used]

	MONROE BASIN			HARPER BASIN		
	Residential	**Glenway**	**Monroe Street**	**Nova**	**Luster**	**Woodward**
Traffic intensity	Low	Medium	High	Low	Low	Low
Overhead tree canopy	Medium	Medium	Medium	Low	Medium	High
Street texture	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Smooth
Street length (curb-miles)	2	0.564	0.281	1.58	14.88	0.56
Parking density	Light	Light	Light	Light	Light	Light
Street cleaning	--	Every 4 weeks	One pass every week	Every 4 weeks	Every 4 weeks	Every 4 weeks

Table B2. Concentrations used by the Source Loading and Management Model prior to calibration with Madison data

[mg/L, milligrams per liter; --, a series of algorithms and coefficients to calculate a street solids concentration are used in model calibration]

Source Area	Suspended solids (mg/L)		Dissolved phosphorus (mg/L)		Particulate phosphorus (mg/L)	
	Residential	**Commercial**	**Residential**	**Commercial**	**Residential**	**Commercial**
Driveways	276	400	0.10	0.10	580	580
Lawns	63	300	.22	.22	1,250	1,250
Parking lots	991	1,630	.02	.02	580	2,960
Streets	--	--	.39	.39	650	650
Woodlots	250	5,000	.25	.25	695	695
Roofs	12	5	.04	.04	1,600	1,000
Sidewalks	12	50	.60	.60	995	995